Symptoms of Overtraining in Resistance Exercise: International Cross-Sectional Survey

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Symptoms of Overtraining in Resistance Exercise: International Cross-Sectional Survey

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Keywords:	fatigue, overreaching, overtraining, resistance training, strength training

ABSTRACT

Purpose: To provide details on the nature and symptomatic profile of training maladaptation in competitive resistance-based athletes to examine whether there are symptoms that may be used as prognostic indicators of overtraining. Identifying prognostic tools to assess for training maladaptation is essential for avoiding severe overtraining conditions.

Methods: A web-based survey was distributed to a cross-sectional convenience sample of competitive athletes involved in sports with a significant resistance training component. The 46 item anonymous survey was distributed via industry experts and social media from July-August 2019.

Results: The final sample included 605 responses (completion rate: 84%). Seventy-one percent of respondents indicated that they had previously experienced an unexplained decrease in performance. Among those, the majority reported a performance decrement lasting from 1 week – 1 month (43.8%). General feelings of fatigue were the most frequent self-reported symptom of maladaptation. Acute training maladaptation, lasting <1 month, was also accompanied by symptoms of musculoskeletal aches and pain. In the majority of cases (92.5%) training maladaptation was accompanied by additional non-training stressors. A greater proportion of respondents with more severe maladaptation (>4 months) were training to muscular failure.

Conclusion: The results from this study support the multifactorial nature of training maladaptation. The multidimensional nature of fatigue and individual variability in symptomatic responses precludes definitive prognostic symptoms or differential diagnostic factors of functional/non-functional overreaching or the overtraining syndrome in resistance exercise.

Keywords: *fatigue, overreaching, overtraining, resistance training, strength training*

INTRODUCTION

Resistance training is often undertaken by athletes who strive to improve muscular strength, hypertrophy and power.[1] It is well-accepted that resistance training can enhance an athlete's ability to perform general sporting skills (e.g. jumping and sprinting) which may result in superior competition performance during sport specific tasks.[2] However, designing an optimal resistance training program is a complex process that involves the careful manipulation of several training variables (e.g. training load, volume, frequency, rest periods and exercise selection).[3] Intensified resistance training in combination with inadequate recovery can result in a decline in performance with or without related physiological and/or psychological signs and symptoms.[4] Resulting maladaptive conditions may include functional overreaching (FOR), non-functional overreaching (NFOR) or the overtraining syndrome (OTS). The well-accepted definitions of Meeusen et al[5] suggest that the differential diagnosis of these conditions is based on the time required for performance restoration. Additionally, it has been suggested that complete performance restoration may not ever be possible with the OTS.[2] However, as current diagnostic criteria has been established through the study of overtraining in endurance activities it is unknown whether these definitions are compatible with such conditions in resistance training.

The prevention and early diagnosis of maladaptive conditions is critical as there are no firmly established therapeutic agents (other than rest) capable of reversing the detrimental effects of overtraining.[5] Many previous studies have searched for prognostic and diagnostic markers that may be used to determine the onset or presence of overtraining (for review, see Meeusen et al[5]). It has previously been established that considerable variability exists in the way that individuals respond to resistance exercise stress.[6] Contextual factors and non-training stressors such as environmental, physical and/or emotional stressors, including insufficient calorie intake, pressure to perform, inadequate nutrition, insufficient sleep or excessive socio-economic concerns may result in large interindividual variability of stress symptoms.[7, 8] In a recent study designed to examine overtrained athletes, Cadegiani et al[9] identified a unique combination of clinical and biochemical manifestations in each individual affected. Furthermore, this study demonstrated a relationship between additional non-training stressors or contextual factors and susceptibility to overtraining. Additionally, in a synopsis of previous literature Fry et al[10] listed 84 major symptoms and manifestations of overtraining in a variety of sports. Determining which signs and symptoms to monitor from such an extensive list continues to challenge both coaches and athletes.

Estimates of the prevalence of overtraining have varied widely depending on the authors' definition of overtraining, the population and the study methodology. It has previously been suggested that endurance- and resistance-trained athletes respond differently to training stress.[4] Early studies imply that athletes involved in primarily anaerobic activities may be more susceptible to overtraining than

endurance based athletes.[11, 12] However, much of the early overtraining literature in resistance exercise was limited to anecdotal accounts with inconsistent use of definitions making quantification of prevalence difficult.[12] Additionally, majority of previous overtraining studies have included only male participants.[13] At present, information concerning overtraining prevalence, potential mechanisms and symptomatology in resistance-trained athletes is scarce.

Many previous studies that have investigated the mechanisms and manifestation of overtraining in resistance exercise have failed to appropriately establish FOR, NFOR or OTS (for review, see Grandou et al[13]). Therefore, the objective of the present exploratory study is to identify possible prognostic symptoms of training maladaptation in resistance exercise. Determining the point at which training becomes maladaptive is of key practical significance for athletes and coaches. At present, the correct diagnosis of maladaptive conditions can only be made retrospectively. Therefore, if prognostic symptoms of overtraining can be identified, remedial reductions in training stress can be implemented and training maladaptation may be avoided.

METHODS

An open international survey was used to identify the symptoms of unexplained training maladaptation amongst competitive athletes in resistance-based sports. Detailed methods according to the Checklist for Reporting Results of Internet E-Surveys (CHERRIES)[14] are available in Table S1. This study was approved by the Human Research Ethics Committee of the University of Technology Sydney (ETH19-3898).

Survey Development

An anonymous survey was developed on REDCap (Research Electronic Data Capture software version 8.11.3 – University of Technology Sydney), a secure web application for building and managing online surveys. The survey was created by the authors in conjunction with a multidisciplinary team of experts in overtraining and resistance training who provided feedback. In order to establish the content validity and reduce response bias the first draft of the survey was piloted with a convenience sample of 24 athletes who participate in resistance-based sports. Based on the resulting feedback, the survey was modified to improve its content, clarity, readability and overall quality. The revised survey was further piloted on a focus group of 6 participants (industry experts and athletes). Based on feedback from the pilot testing the content and format of the survey was further refined. Finally, the authors completed a heuristic evaluation to establish the usability of the survey interface on various devices (PC, Macintosh, iPhone, Android).

The final survey consisted of 46 items distributed between 5 sections: (1) demographic information, (2) strength, (3) performance, (4) training, (5) symptoms and (6) recovery (Table 1). The survey concluded at stage (3) for subjects that indicated that they have never experienced an unexplained decline in performance. Both open-ended and dichotomous questions were included throughout the survey. In order to avoid acquiescence bias, respondents were not prompted by pre-loaded questions asking if they did/did not experience a particular symptom. Such questions increase the likelihood of participants falsely reporting the presence of a symptom that may not have experienced. Rather, respondents were required to self-report their symptoms in open text boxes. The survey was available in 4 languages (English, Italian, Portuguese and Spanish). Native speakers assessed the validity of each translation based on the original English survey.

INSERT TABLE 1 ABOUT HERE

Sample Selection & Administration

A voluntary convenience sample of competitive athletes involved in sports with a resistance training component were recruited. Eligible sports were categorised into 'resistance exercise only' sports (powerlifting, bodybuilding, weightlifting and strongman) and 'resistance exercise combined' sports (CrossFit, rugby, sprinting, hurdles, long/triple/high jump, shot put, javelin, discus and pole vault). Collectively, respondents will be referred to as 'resistance-based athletes'. Participants must have competed in their respective sports, however, no restriction was placed on the level of competition (i.e. club to international level athletes).

Respondents were recruited through various means from July to August 2019 to obtain a sample of approximately one thousand responses. The primary methods of recruitment were through emails distributed to industry experts in relevant sports/disciplines and by direct sharing of a survey recruitment flyer on social media (Figure S1). In order to avoid sampling bias, terms related to 'overtraining' and 'overreaching' were not used in the survey advertisement or until section (6) of the survey. Thus, reducing the likelihood that the resulting sample over represents individuals who have strong opinions or experiences with overreaching and overtraining.

Statistical Analysis

Statistical analysis of the anonymous data set were conducted using IMB SPSS v25 (2019). Missing data checks were conducted to confirm data integrity. Frequencies were calculated for respondents demographic and training characteristics, respondents were categorised according to their respective

sport/discipline (resistance exercise only and resistance exercise combined). The proportion of athletes who reported that they had previously experienced an unexplained decrease in performance were tabulated. Bivariate statistics (chi-square analyses) were used to determine whether experiences of training maladaptation varied by training history and/or training style.

RESULTS

Among the 961 online survey views, 760 responded (84% completion rate) (Figure 1). Following the exclusion of recreational athletes and those that were involved in non-eligible sports the final sample size included 605 responses. Overall, 70.9% of participants indicated that they had previously experienced an unexplained decrease in competition performance (Table 2). The majority of respondents (76.5%) were involved in resistance exercise only sports (powerlifting, weightlifting and bodybuilding). Demographic characteristics of participants are summarised by sporting category in Table 3.

INSERT FIGURE 1 ABOUT HERE

INSERT TABLE 2 ABOUT HERE

INSERT TABLE 3 ABOUT HERE

Among the participants that indicated that they had previously experienced an unexplained decrease in performance, 70.9% were indicative of acute maladaptation indicating possible acute fatigue, FOR or NFOR (<1 week=26.8%, 1 week – 1 month=43.8%) (Figure 2). Only 17.8% of responses were reflective of chronic training maladaptation indicating possible NFOR or OTS (1-3 months=13.1%, >4 months=4.7%). No interaction effect was found between how many years participants had been training and unexplained decreases in performance ($p=0.259$). However, findings showed that a greater proportion of participants with more severe training maladaptation (>4 months) reported training to muscular failure (Figure 3). The majority of participants who had experienced a decline in performance also reported experiencing additional stress outside of training (92.5%). The most commonly reported stressor was work (25.5%) followed by personal life (23.2%) and external factors such as dieting/negative energy balance (22.9%) (Table 4).

INSERT FIGURE 2 ABOUT HERE

INSERT FIGURE 3 ABOUT HERE

INSERT TABLE 4 ABOUT HERE

The most reported symptoms for each duration of training maladaptation are displayed in Figure 4. A complete list of symptoms and frequency of reporting can be found in Table S2. General feelings of fatigue were the most common self-reported symptom overall (n=153, 35.7%) and in each time frame of training maladaptation (<1 week n=48, 28.9%; 1 week – 1 month n=74, 27.0%; 1-3 months n=25, 25.5%; >4 months n=6, 22.2%). Musculoskeletal aches and pain were the second most frequent self-reported symptom for acute maladaptation to training (FOR: n=15, 9.0%; NFOR: n=25, 9.1%).

INSERT FIGURE 4 ABOUT HERE

DISCUSSION

Finding the optimal balance between training and recovery in order to enhance athletic performance and simultaneously avoid maladaptive training conditions continues to challenge both coaches and athletes. Despite the potentially serious implications of overtraining on athletic performance, to date, a decrease in sport specific performance, that cannot be explained by underlying conditions, is the only diagnostic marker.[13] The purpose of this study was to provide details on the nature and symptomatic profile of training maladaptation in competitive resistance-based athletes to examine whether there are symptoms that may be used as prognostic indicators of overtraining. A greater understanding of the symptomatic profile of maladaptation in resistance-based athletes may allow for the development of valid, reliable and objective prognostic and diagnostic tools that do not involve maximal performance tests. This is the first global survey of experiences and self-reported symptoms of unexplained underperformance in a large sample of competitive resistance-based athletes across 50 countries.

Previous studies have suggested that training maladaptation is a significant problem in resistance-based sports.[11] The purpose of the present study did not include the determination of the prevalence or incidence of overtraining conditions in resistance exercise. However, a significant number of respondents indicated that they had previously experienced an unexplained decline in performance (70.9%). The majority of athletes reported a performance impairment that lasted between 1 week and 1 month (43.8%). A decline in performance of this duration may be reflective of FOR or NFOR, in accordance with the well-accepted presentation of stages of overtraining.[5] Based on this classification, in our sample, the proportions of respondents reporting a decline in performance of more than 4 months

(i.e. potentially indicative of severe OTS) was relatively low (4.7%). The low proportion of long-term underperformance, compared to overall prevalence of training maladaptation is consistent with previous literature which suggests that cases of the OTS are less common.[4] However, the differential diagnosis of FOR, NFOR or OTS based on survey responses is beyond the scope of this paper. Due to the continuous nature of overtraining defining the cut-off point between FOR, NFOR and OTS based on the proposed definitions of Meeusen et al[5] is difficult. Examination of the appropriateness of using similar diagnostic criteria (time-frame of performance decline) for both endurance- and resistance-based sports should be considered.

The detrimental effects of overtraining on athletic performance has led to the search for prognostic symptoms that can be used to prevent imminent overtraining. However, self-reported symptom prevalence has not been studied in competitive athletes involved in resistance-based sports. Determination of the most frequent self-reported symptoms of training maladaptation is of key practical significance for athletes and coaches in resistance-based sports as it may provide a simple tool, that does not require physical tests or biochemical analysis, to assess both training and competition performance. Subjective feelings of general fatigue were the most common self-reported symptom in this study regardless of the duration of training maladaptation. Athletes and coaches should attempt to monitor for subjective feelings of fatigue during periods of high training load to monitor for possible maladaptation. However, the symptom of fatigue is poorly defined and therefore careful inquiry is needed to distinguish lack of energy from exhaustion or sleepiness.[15] Furthermore, it is unclear whether the general symptom of fatigue is a physiological response, psychological perception or symptom of physical or psychiatric disorders.[16] The multidimensional nature of fatigue introduces difficulties in quantifying the subjective feeling. Future studies should test or develop appropriate instruments to differentiate acute from chronic fatigue.

It is difficult to separate the symptoms of overtraining with those of normal fatigue that may result from high intensity and/or volume training sessions which are necessary to promote physiological adaptations. Although the decline in performance associated with overtraining appears to be accompanied by symptoms of generalised fatigue, the presence of fatigue is not necessarily synonymous with forthcoming training maladaptation. A multidimensional approach to the assessment and monitoring of training maladaptation is likely required. Athletes and coaches should regularly monitor a combination of performance and symptomatic variables to identify athletes that may be approaching FOR, NFOR or OTS. However, the diagnostic criteria of maladaptive conditions remains a decline in maximal performance lasting ‘days-weeks’ for FOR, ‘weeks-months’ for NFOR and ‘months…’ for OTS.[5] Accordingly, an accurate diagnosis can only be made retrospectively, once confounding factors that may be attributed to the decline in performance have been excluded.[5]

Apart from fatigue, a variety of secondary psychological and physiological symptoms were reported by athletes, the expression of which varying depending on the individual, training methods and other contextual factors. Musculoskeletal aches and pains were a frequent complaint of respondents who reported acute durations of training maladaptation (<1 week and 1 week – 1 month). Although the etiology of musculoskeletal aches and pain is multifactorial, there is a general consensus that repeated loading of high forces may create the potential for acute joint or musculotendinous injury.[17] These results may suggest that an imbalance between training and recovery may result in acute musculoskeletal pain responses, such as swelling or micro trauma to tissues. However, these responses are likely to be transient as musculoskeletal aches and pain were not among the most reported symptoms in chronic maladaptive conditions (1 – 3 months and >4 months). These findings are supported by Cadegiani et al[18] who reported that impaired muscle recovery may be a characteristic of the OTS. During periods of high intensity resistance training, athletes and coaches should monitor subjective symptoms of musculoskeletal aches and pain as chronic maladaptation to training may be avoided if sufficient recovery is implemented.

Given the heterogeneity and variability of symptoms of overtraining in resistance exercise and the present state of research, a single symptom that can be used to predict ensuing overtraining is unlikely. The interindividual variability of the symptoms of overtraining as well as the variable nature of the stressors that may cause overtraining suggest the need for a variety of parameters as markers of training maladaptation. The results of this survey suggest that, at present, no particular symptomatic profile can be used to distinguish between maladaptive conditions (FOR, NFOR and OTS) in resistance-based athletes. This may be due to the variability of symptoms or the proposed continuum theory of training maladaptation. If overtraining exists on a continuum it may be difficult to differentiate between the symptoms of acute fatigue, overreaching and overtraining. Kuipers et al[19] suggest that symptoms of overtraining in endurance activities appear progressively as fatigue accumulates. Future studies should seek to evaluate the severity and progression of symptoms in resistance-based athletes at different stages of overreaching and overtraining.

The pathogenesis of maladaptation in resistance-based sports is not completely understood. However, it is well-established that causes of training maladaptation are multifactorial.[5, 9] In agreement with previous research in endurance activities,[20, 21] the present findings suggest that a combination of training and non-training stressors are present at the time of resistance training maladaptation. The vast majority (92.5%) of athletes experiencing an unexplained decline in performance also reported experiencing additional stress outside of training. Similarly, Cadegiani et al[9] identified a relationship between susceptibility to maladaptation and non-training stressors. These findings suggest that training maladaptation is not only the result of excessive physical training. Coaches and athletes should be aware of potential stressors outside of training including caloric and macronutrient intake as well as concurrent

cognitive demands. Additional social and environmental stressors must be considered and managed appropriately to prevent training maladaptation. Therefore, regular psychological assessment of athletes who complete intensive resistance training may provide benefits by detecting early symptoms of maladaptive training.

A large proportion of athletes with a decrease in performance lasting greater than 4 months reported training to muscular failure (65%). This finding suggests that severe maladaptation is associated with high intensity resistance training to muscular failure. Previous studies have suggested that high intensity training may increase susceptibility to overtraining in resistance exercise.[13, 22] However, at present no previous study has examined how training to muscular failure may impact the etiology of overtraining in resistance exercise. It is well-accepted that there is interindividual variability in the way that athletes tolerate increases in training load, training intensity and, competition and non-training stress.[6] Therefore, training load and intensity must be individualised depending on each athlete's response.

Limitations

This is the first global survey of maladaptation to training in resistance-based sports. However, there are limitations to this study that must be acknowledged. The main limitation of this study was the self-reported quantification of performance decrements. Possible inter-participant variability in the determination of an unexplained decrease in performance and recency bias should be considered when interpreting the findings of this study. For example, low energy availability resulting in relative energy deficiency in sport may have contributed to a decline in performance that participants unknowingly interpreted as 'unexplained underperformance'. Future studies are required to understand eating patterns as additional stressors in relation to overtraining in resistance exercise. Study participants were drawn from a convenience sample and restricted to competitive resistance-based athletes, therefore findings cannot be generalised to non-competitive athletes or endurance athletes. In addition, this study adopted a cross-sectional design precluding any causal inferences (causal link with symptoms). Furthermore, no precautionary measures were used to prevent multiple entries from the same individual. Caution should be used when comparing athletes undertaking resistance exercise only or combined training, it is unknown whether resistance exercise only participants were engaging in additional aerobic exercise at the time of maladaptation. The difficulties and ethical considerations of studying overtraining in athletic populations are appreciated, however, well-designed studies are required to gain a greater understanding of maladaptive training conditions in resistance-based athletes.

Practical Applications

The purpose of this study was to provide details on the nature and symptomatic profile of training maladaptation in competitive resistance-based athletes to examine whether there are symptoms that may be used as prognostic indicators of overtraining. Considering that overtraining is likely associated with the duration and severity of symptoms rather than a singular symptom, practitioners should routinely and systematically assess fatigue, musculoskeletal pain and non-training stressors during periods of high training load and/or intensity. The development of valid and reliable questionnaires or other diagnostic measures in athletic populations are required for assessing fatigue and additional symptoms related to training maladaptation. The persistence of such symptoms may be indicative of a negative progression in training. Given the multifactorial nature of the etiology and symptoms of overtraining, future studies are required to gain a greater understanding of the underlying mechanisms of training maladaptation. Well-designed studies with demonstrated decreases in performance and follow-up measures are required for the development of causal assumptions of overtraining for use in future prognostic studies.

Conclusion

Overtraining conditions are characterised by an imbalance between training as well as non-training stress and recovery. Maladaptive conditions may present with a wide range of clinically significant symptoms such as fatigue, musculoskeletal aches and pain, loss of motivation, insomnia and/or other physical or psychological symptoms. Subjective feelings of fatigue are likely to accompany training maladaptation in resistance exercise. However, the results from this exploratory study do not permit causal conclusions. It is evident that the accompanying symptoms of training maladaptation may be variable in nature. The multidimensional nature of fatigue and individual variability in symptomatic responses precludes the definitive prognosis or differential diagnosis of FOR, NFOR or OTS in resistance exercise. At present, the correct diagnosis of overreaching and overtraining in resistance exercise remains a demonstrated decrease in maximal performance capacity.

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356 and Lee Bell declare that they have no conflicts of interest relevant to the content of this study.
357
358 **Data Availability Statement:** The raw and coded data that support these findings of this study are
359 available from https://osf.io/je2rf and https://osf.io/bgxpa, respectively.

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Table 1. Survey Instrument.

Field	Answer Choice
1. Demographics	
Country	Country dropdown
Gender	1, Male 2, Female 3, Other
Age	Numerical
Body weight (kg)	Numerical
Height (cm)	Numerical
What sport or discipline do you compete in?	1, Weightlifting 2, Powerlifting 3, Strongman 4, Bodybuilding 5, Sprinting 6, Hurdles 7, Long jump 8, Triple jump 9, High jump 10, Shot put 11, Javelin 12, Discus 13, CrossFit 14, Rugby Union 15, Rugby League 16, American Football 17, Pole Vault 18, Other
If "other", please specify	Open
How many years have you been training in your sport?	Numerical
What is the highest level you have competed at?	1, Club 2, Regional 3, State 4, National 5, International 6, Other
2. Strength	
Load SQUAT: What is the maximum weight you have lifted for a given amount of repetitions? (i.e. 100kg for 1RM or 75kg for 3RM etc.) (kg)	Numerical
Repetitions?	Numerical
Load BENCH PRESS: What is the maximum weight you have lifted for a given amount of repetitions? (i.e. 100kg for 1RM or 75kg for 3RM etc.) (kg)	Numerical
Repetitions?	Numerical
3. Performance	
Have you ever experienced an unexplained decrease in performance?	1, Yes 2, No (survey termination if "No")
4. Training	
How many times have you experienced this?	1, Once 2, Twice 3, Three or more times
Please answer the following questions in reference to your most severe case (if more than once)	

How was your performance affected?	1, Decreased strength 2, Decreased running speed 3, Blunted hypertrophy 4, Increased perception of effort while training 5, Decrease in sport performance (e.g. jump height, throwing, sprint) 6, Other
If "other", please specify	Open
How long did the decrease in performance last? (i.e. when did your performance return to normal?)	1, < 1 week 2, 1 week - 1 month 3, 1 - 3 months 4, > 4 months
Leading up to the decline in performance how many times per week were you performing resistance training?	Open
What was the average duration of each resistance training session?	1, < 1 hour 2, 1-2 hours 3, >2 hours
Leading up to the decline in performance were you also performing technical/skill training?	1, Yes 2, No
Leading up to the decline in performance were you also performing metabolic and/or conditioning training?	1, Yes 2, No
Which option best describes the INTENSITY of resistance training you were performing at the time you experienced the decline in performance?	1, heavy loads to muscular failure 2, heavy loads without muscular failure 3, light loads to muscular failure 4, light loads without muscular failure
Which option best describes the VOLUME of resistance training you were performing at the time you experienced the decline in performance?	1, high repetitions, high sets 2, high repetitions, low sets 3, low repetitions, high sets 4, low repetitions, low sets
How frequently were you training each muscle group?	1, 1 time per week 2, 2 times per week 3, 3 times per week 4, >3 times per week
Leading up to/during this period, were you experiencing any other non-training stress?	1, Dieting (calorie restriction) 2, Private life stress 3, Work-related stress 4, Other non-training stressors 5, None of the above 6, Viral infection 7, Mental health condition
5. Symptoms	
Symptoms	Open
Please rate the severity of the symptoms above	Insignificant | Extreme
Did you also experience any of these symptoms before you noticed the decline in performance?	Open
Did you experience any other symptoms during this period?	Open
Please describe the other symptoms you experienced	Open
6. Recovery	
Did you seek help/search for information when this occurred?	1, No 2, Yes – Doctor 3, Yes - Coach 4, Yes - Internet/web-sources 5, Yes – Other
What recovery/training strategies did you use in order to return performance to normal?	1, Decrease training intensity 2, Decrease training frequency

	3, Decrease training volume 4, Increase calorie intake 5, Eliminate stressful contextual (non-training) factors 6, Supplementation 7, Medicine/seek medical help 8, Other
If "other", please specify	Open
Would you define this period as	1, Overtraining 2, Overreaching 3, Acute fatigue 4, Other

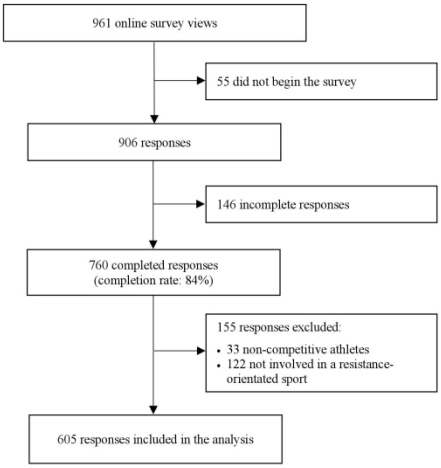

Figure 1. Sample selection.

Figure 1. Sample selection

210x297mm (300 x 300 DPI)

Table 2. Frequency of self-reported unexplained decrease in performance.

Category	Sport/discipline	Total	Decrease in performance	No decrease in performance
RE only	Powerlifting	231	69.3%	30.7%
	Bodybuilding	138	76.0%	24.0%
	Weightlifting	71	76.0%	24.0%
	Strongman	23	47.8%	52.2%
	Total	*463*	*71.3%*	*28.7%*
RE combined	Rugby	54	63.0%	37.0%
	CrossFit	42	81.0%	19.0%
	Sprint	21	66.7%	33.3%
	American Football	10	60.0%	40.0%
	Hurdles	4	50.0%	50.0%
	Javelin	3	66.7%	33.3%
	Long jump	3	100.0%	0.0%
	Shot put	2	100.0%	0.0%
	Discus	1	0.0%	100.0%
	Pole vault	1	100.0%	0.0%
	Triple jump	1	100.0%	0.0%
	Total	*142*	*69.7%*	*33.3%*
Combined Total		**605**	**70.9%**	**29.1%**

RE, resistance exercise.

Table 3. Descriptive characteristics of 605 respondents.

Characteristic	RE only n (±SD)	RE combined n (±SD)	Total n (±SD)
Male	340	112	452
Female	123	30	153
Age (years)	29.7 (9.05)	28.0 (9.04)	29.27 (9.07)
Weight (kg)	82.37 (18.11)	84.06 (20.1)	83.53 (18.59)
Height (cm)	173.95 (8.79)	178.25 (12.45)	174.96 (9.93)
Training years (years)	4.45 (2.89)	6.54 (3.14)	4.94 (3.08)
Squat 1RM (kg)			
Male	178.62 (45.05) Range: 50-300	161.73 (44.29) Range: 30-290	174.37 (45.40) Range: 30-300
Female	116.48 (33.25) Range: 55-215	99.89 (27.35) Range: 60-174	113.54 (32.77) Range: 55-215
Bench press 1RM (kg)			
Male	125.69 (30.97) Range: 50-265	115.93 (28.64) Range: 20-200	123.28 (30.67) Range: 20-265
Female	69.97 (20.85) Range: 28-155	52.15 (13.41) Range: 25-85	66.85 (20.86) Range: 25-155
Competition level			
Club	166	33	149
Regional	90	22	112
State	54	12	66
National	141	50	191
International	62	25	87

RE, resistance exercise; *1RM,* one repetition maximum.

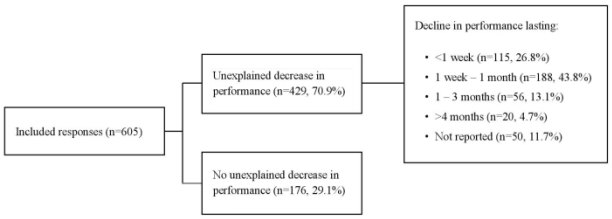

Figure 2. Flow chart of maladaptation to training responses.

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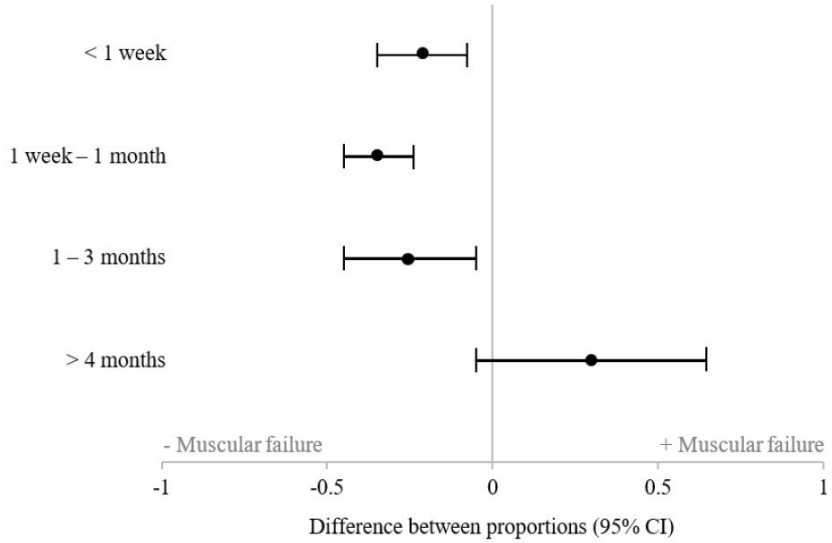

Figure 3. Difference between the proportions of participants training to muscular failure and participants training without muscular failure by the severity of training maladaptation.

Figure 3. Difference between the proportions of participants training to muscular failure and participants training without muscular failure by the severity of training maladaptation

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Table 4. Dichotomous frequency of additional stressors in respondents experiencing training maladaptation.

Additional stressor	**'Yes' responses** N(%)				
	<1 week	**1 week – 1 month**	**1-3 months**	**>4 months**	**Total**
Work	53 (48.1)	86 (48.5)	29 (54.7)	9 (45.0)	177 (25.5)
Life	48 (43.6)	76 (42.9)	28 (52.8)	9 (45.0)	161 (23.2)
Dieting	49 (44.5)	78 (44.0)	23 (43.4)	9 (45.0)	159 (22.9)
Other	21 (19.0)	36 (20.3)	9 (16.9)	4 (20.0)	70 (10.1)
Mental health	20 (18.1)	22 (12.4)	15 (28.3)	4 (20.0)	61 (8.8)
Virus	5 (4.5)	4 (2.2)	4 (7.5)	2 (10.0)	15 (2.2)
No additional stressors	20 (18.1)	23 (12.9)	5 (9.4)	4 (20.0)	52 (7.5)

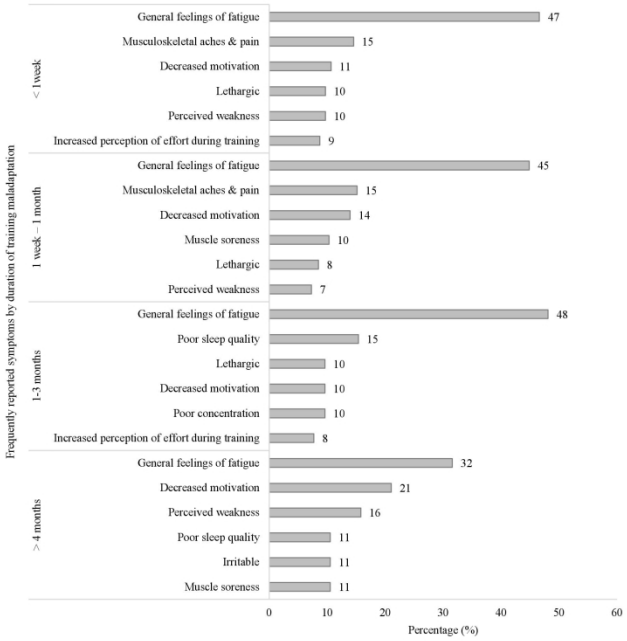

Figure 4. Most frequent self-reported symptoms of training maladaptation.

Figure 4. Most frequent self-reported symptoms of training maladaptation

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Table S1. Checklist for Reporting Results of Internet E-Surveys (CHERRIES) [7].

Item category	Checklist Item	Description
Design	Describe survey design	An open cross-sectional international survey was used to identify the prevalence, predicting factors and symptoms of overreaching and overtraining amongst competitive athletes in resistance based sports. The target population was competitive athletes involved in sports with a resistance training component. Eligible sports included powerlifting, bodybuilding, weightlifting, CrossFit, strongman, rugby, sprinting, hurdles, long/triple/high jump, shot put, javelin, discus and pole vault. Subjects must have competed in their respective sports, no restriction was placed on the level of competition (i.e. club to international level athletes). A voluntary non-randomised convenience sample was recruited. Due to the extremely large eligible population, sample randomisation was not possible.
Ethics	Ethics approval	Ethics approval was obtained from the Human Research Ethics Committee of the University of Technology Sydney (ETH19-3898).
	Informed consent	The survey was voluntary and anonymous. Therefore, consent was deemed to be given by beginning the online survey. The banner advertisement included information about the length of the survey and the voluntary/anonymous nature of the survey. The banner advertisement also have an email address that participants were encouraged to contact if they required further information regarding the purpose of the study, identity and qualifications of investigators etc.
	Data protection	REDCap (Research Electronic Data Capture Software Version 8.11.3 – University of Technology Sydney), a secure web application was used to develop and managing this survey. The survey was anonymous, no personal information was linked to the survey results. Data did require de-identification as the survey contained no identifiable questions. The dataset was kept on password protected computers.
Development and pre-testing	Development and testing	The survey was developed by the authors in conjunction with a multidisciplinary team of experts in overtraining and resistance training providing feedback. In order to establish the content validity and reduce response bias the first draft of the survey was piloted with a convenience sample of 24 athletes who participate in resistance-based sports. Based on the resulting feedback, the survey was modified to improve its content, clarity, readability and overall quality. The revised survey was further tested on a focus group of 6 people (industry experts and athletes). Based on feedback from the focus group the content and format of the survey was further refined. Finally, the authors completed a heuristic evaluation to establish the usability of the survey interface on various devices (PC, Macintosh, iPhone, Android). The final survey consisted of 46 items divided between 5 sections: (1) demographic information, (2) strength, (3) performance, (4) training practices, (5) symptoms, (6) recovery. The survey

Item category	Checklist Item	Description
		contained both open-ended and closed questions with response scales. The survey was translated by native speakers into 4 languages; English, Italian, Portuguese and Spanish.
Recruitment process and description of the sample having access to the questionnaire	Open vs closed survey	This was an open survey.
	Contact mode	Not applicable. Potential participants were not contacted.
	Advertising the survey	Survey recruitment was achieved in multiple ways, predominately through banner advertisements, contacting industry experts, sharing via social media and posting in online communities. A banner advertisement was posted with a link to the online survey on Twitter, Instagram and Facebook. The ad was reposted by industry contacts approximately 50 times collectively across all social media platforms. In order to avoid voluntary response bias, terms related to overtraining and overreaching were not used in the survey advertisement. Therefore, reducing the likelihood that the sample may over represent individuals who have strong opinions or experiences with overtraining.
Survey administration	Web/E-mail	This was a web-based survey, with respondents gathered through social media advertisement. Responses were collected through the secure online survey platform REDCap and stored on secure local servers. Responses included open-ended, multiple choice and response scales.
	Context	The survey advertisement was shared by industry experts (e.g. sports science researchers, coaches of eligible sports, athletes involved in eligible sports). The survey was also shared among online communities on Facebook (e.g. Weightlifting Australia, Bodybuilding forums). Therefore, the survey would have likely only captured individuals active on social media. However, this would likely not contribute to response bias. Wording of the survey advertisement was carefully selected to not include terms related to overtraining and overreaching to further reduce the likelihood of response bias.
	Mandatory/voluntary	Voluntary.
	Incentives	Respondents were not incentivised for their participation.
	Time/date	Responses were collected over two months from 24 July to 23 August, 2019.
	Randomisation of items	No randomisation of items was used.
	Adaptive questioning	Adaptive questioning (branched logic) was used throughout the survey to reduce the number and complexity of questions. Certain questions were only relevant for specific populations (e.g. those who indicated that they compete in bodybuilding were further prompted to indicate whether they competed in a natural bodybuilding federation or non-natural bodybuilding federation). Additionally, a stop action was in place on page three where those who indicated that they had never experienced an unexpected decline in performance were required to end the survey. Respondents who indicated that they had experienced an unexplained decrease in performance were required to continue on with the survey.

Item category	Checklist Item	Description
	Number of items	The full survey comprised a total of 46 items, although because of the adaptive nature of the survey, not all respondents answered all items.
	Number of screens	The entire survey was distributed over 6 pages.
	Completeness check	A completeness check was completed after responses were submitted. Page 3 was deemed mandatory *"Have you ever experienced an unexplained decrease in performance?"* Drop off was low at 16%. Most items, except demographic questions and those items required for adaptive questioning included an 'other' or 'don't know' option.
	Review step	Respondents were able to change their responses on previous screens through a 'Back' button whilst they were completing the survey. However, respondents were unable to change their responses once submitted. The beginning of the survey was preceded by the sentence *"Please ensure that you have time to complete the entire survey before beginning as you cannot save your responses and return at a later time."*
Response rates	Unique site visitor	Not applicable. Open survey.
	View rate	961 online survey views
	Participation rate	Not applicable. Open survey.
	Completion rate	Of the 906 respondents who commenced the survey, 760 completed it, giving a completion rate of 84%. 155 responses were excluded due to eligibility criteria (competitive athletes in resistance-based sports).
Preventing multiple entries from the same individual	Cookies used	Not used.
	IP check	Not used.
	Log file analysis	Not used.
	Registration	Not used.
Analysis	Handling of incomplete questionnaires	Only responses completed up until the third screen where a stop action was in place were included in the final dataset. Respondents who indicated they had experienced an unexplained decrease in performance were prompted to continue to answer questions about their experience. Respondents who indicated that they had never experienced an unexplained decrease in performance were prompted to finish the survey.
	Questionnaires with atypical timestamp	No respondents were removed from the data set for atypical completion times.
	Statistical correction	No methods such as weighting of items or propensity scores were used to adjust for the non-representative sample.

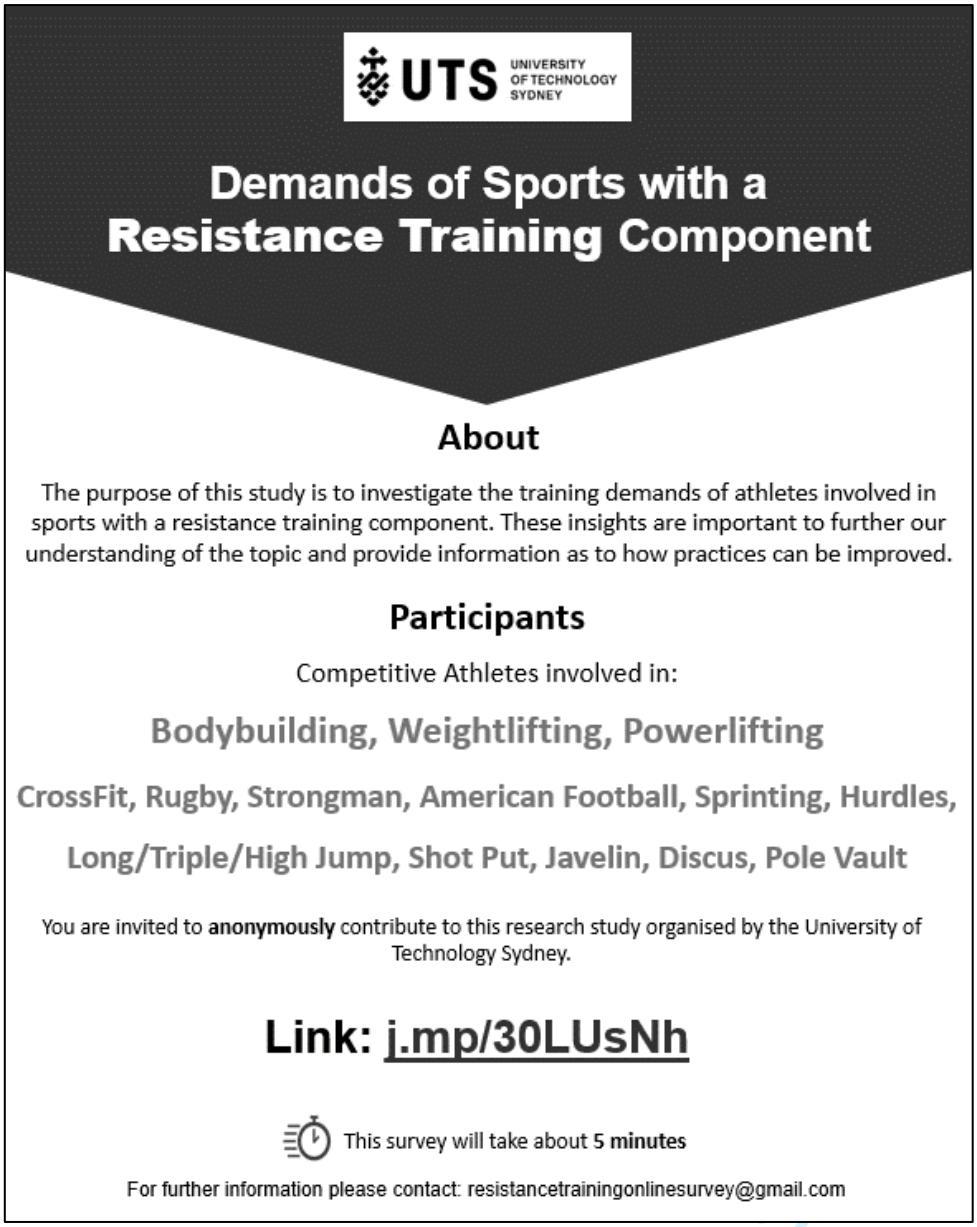

Figure S1. Survey Advertisement.

Table S2. Symptoms.

Duration of training maladaptation	Symptom	Frequency of reporting (n)	Frequency of reporting
<1 week	General feelings of fatigue	48	28.9%
	Musculoskeletal aches and pain	15	9.0%
	Decreased motivation	11	6.6%
	Lethargic	10	6.0%
	Perceived weakness	10	6.0%
	Increased perception of effort during training	9	5.4%
	Muscle soreness	8	4.8%
	Poor sleep quality	6	3.6%
	Depression	5	3.0%
	Stress	5	3.0%
	Emotional instability	5	3.0%
	Irritable	4	2.4%
	Anxiety	3	1.8%
	Decreased appetite	3	1.8%
	Poor concentration	3	1.8%
	Light headedness	3	1.8%
	Flu-like illness	2	1.2%
	Digestive discomfort	2	1.2%
	Injury	2	1.2%
	Excessive perspiration	2	1.2%
	Headaches	2	1.2%
	Inflammation	2	1.2%
	Decreased libido	1	0.6%
	Weight gain	1	0.6%
	Slowed recovery	1	0.6%
	Increased appetite	1	0.6%
	Loss of coordination	1	0.6%
	Decreased hypertrophy	1	0.6%
	Total	**166**	**100.0%**
1 week – 1 month	General feelings of fatigue	74	27.0%
	Musculoskeletal aches and pain	25	9.1%
	Decreased motivation	23	8.4%
	Muscle soreness	17	6.2%
	Lethargic	14	5.1%
	Perceived weakness	12	4.4%
	Emotional instability	11	4.0%
	Poor concentration	9	3.3%
	Poor sleep quality	8	2.9%
	Increased perception of effort during training	8	2.9%
	Irritable	8	2.9%
	Slowed recovery	6	2.2%
	Increased appetite	6	2.2%
	Decreased libido	5	1.8%
	Headaches	5	1.8%
	Light headedness	5	1.8%
	General apathy	5	1.8%

	Anxiety	4	1.5%
	Stress	4	1.5%
	Flu-like illness	4	1.5%
	Depression	3	1.1%
	Decreased appetite	3	1.1%
	Injury	3	1.1%
	Weight loss	3	1.1%
	Increased heart rate	2	0.7%
	Decreased hypertrophy	2	0.7%
	Weight gain	1	0.4%
	Digestive discomfort	1	0.4%
	Amenorrhea	1	0.4%
	Loss of coordination	1	0.4%
	Inflammation	1	0.4%
	Total	**274**	**100.0%**
1 – 3 months	General feelings of fatigue	25	25.5%
	Poor sleep quality	8	8.2%
	Lethargic	5	5.1%
	Decreased motivation	5	5.1%
	Poor concentration	5	5.1%
	Increased perception of effort during training	4	4.1%
	Decreased libido	4	4.1%
	Muscle soreness	4	4.1%
	Anxiety	3	3.1%
	Musculoskeletal aches and pain	3	3.1%
	Emotional instability	3	3.1%
	Flu-like illness	3	3.1%
	Increased appetite	3	3.1%
	Perceived weakness	3	3.1%
	Injury	3	3.1%
	Loss of coordination	3	3.1%
	Slowed recovery	2	2.0%
	Weight loss	2	2.0%
	Headaches	2	2.0%
	Depression	1	1.0%
	Increased heart rate	1	1.0%
	Decreased appetite	1	1.0%
	Stress	1	1.0%
	Irritable	1	1.0%
	Digestive discomfort	1	1.0%
	Light headedness	1	1.0%
	Decreased hypertrophy	1	1.0%
	Total	**98**	**100.00%**
>4 months	General feelings of fatigue	6	22.2%
	Decreased motivation	4	14.8%
	Perceived weakness	3	11.1%
	Poor sleep quality	2	7.4%
	Irritable	2	7.4%
	Muscle soreness	2	7.4%
	Lethargic	1	3.7%
	Depression	1	3.7%

	Anxiety	1	3.7%
	Emotional instability	1	3.7%
	Flu-like illness	1	3.7%
	Injury	1	3.7%
	Inflammation	1	3.7%
	Decreased hypertrophy	1	3.7%
	Total	**27**	**100.00%**