



Original Research

Training volume is associated with pain sensitivity, but not with endogenous pain modulation, in competitive swimmers[☆]

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ABSTRACT

Objectives: To investigate the association of pain sensitivity and endogenous analgesia capacity, and training volume in a group of competitive swimmers.

Design: An observational multi-center study.

Setting: Multiple competitive swimming clubs.

Participants: 102 healthy competitive swimmers.

Main outcome measures: Training volume was estimated using self-reported information. Static and dynamic measures of pain were assessed using pressure pain thresholds (PPTs) and conditioned pain modulation (CPM), the latter as a measure of endogenous pain inhibition. Selected demographic and psychosocial measures were considered as possible confounding factors.

Results: Moderate positive correlations ($0.38 < r < 0.44$; $p < 0.01$) exist between self-reported training volume and PPTs at widespread body areas in competitive swimmers. These results were maintained during linear regression analysis while addressing possible confounding factors such as age and selected psychosocial factors. No associations were found between self-reported training volume and conditioned pain modulation ($-0.08 < r < 0.06$; $p > 0.05$).

Conclusions: Self-reported swim training volume is associated with pain sensitivity in competitive swimmers. Swimmers who train more show higher pressure pain thresholds, indicating lower pain sensitivity. Swim training volume is not associated with endogenous nociceptive inhibitory capacity as determined using CPM.

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1. Introduction

Since pain interferes with performance (Mauger & Hopker, 2012), the question of whether physical training interferes with pain seems relevant for athletes as it implies possible performance enhancement. Acute exercise bouts are known to have temporary endogenous hypoalgesic effects in healthy people and in people suffering local or regional pain problems (Naugle, Fillingim, & Riley, 2012; Kuppens et al., et al.). These temporary pain reducing effects appear during exercise and seem to fade out during 15–30 min after cessation of exercise (Naugle et al., 2012). Furthermore the positive effects of doing exercise on a regular basis on pain in a healthy general population are being established (Jones, Booth,

Taylor, & Barry, 2014; Lemming et al., 2015; O'Leary, Collett, Howells, & Morris, 2017). All together it is clear that both acute bouts and regular exercise have hypoalgesic effects. Evidence even consistently indicates that athletes are more tolerant towards experimental pain when compared to non-athletes (Tesarz, Schuster, Hartmann, Gerhardt, & Eich, 2012a, 2012b). Based on other pain outcomes such as pain thresholds and endogenous analgesic capacity this consistency in the literature disappears (Tesarz et al., 2012a, 2012b). We should however consider a training volume- and intensity dependency that possibly remains underexposed in group comparisons.

Moreover gaining knowledge on the impact of different training variables, such as training volume and intensity seems imperative to unravel questions concerning the possibility to influence pain through specifically tailored physical training (Anshel & Russell, 1994; Jones et al., 2014; Umeda, Lee, Marino, & Hilliard, 2016). O'Leary et al. found that the effect of endurance training on pain tolerance in healthy individuals is intensity dependent (O'Leary et al., 2017). More studies exploring possible associations between specific training variables and pain outcomes are essentially lacking.

Pain is a complex result of both facilitatory and inhibitory endogenous mechanisms, which requires the use of both static (e.g. pain pressure thresholds (PPTs)) and dynamic measures (e.g. conditioned pain modulation (CPM)) in research to draw well-founded conclusions. In this observational study we focus on the relationships between pain thresholds using static (PPTs) and dynamic (CPM) measures of pain, and training volume in a group of competitive swimmers. This group was chosen because competitive swimmers are endurance athletes known to train in stable circumstances with training load being highly volume-dependent. Selected demographic (e.g. age) and psychosocial measures (e.g. data on pain catastrophizing) were considered as possible confounding factors as they might influence an individuals' pain (El Tumi, Johnson, Dantas, Maynard, & Tashani, 2017; Lautenbacher, Peters, Heesen, Scheel, & Kunz, 2017; Lumley et al., 2011; Patanwala et al., 2018; Persad, Kamerman, & Wadley, 2017; Sheffield, Biles, Orom, Maixner, & Sheps, 2000; Vranceanu, Barsky, & Ring, 2009). It is hypothesized that those swimmers who are exposed to higher training volumes are characterized by higher pain thresholds and greater pain modulatory efficiency. To the best of our knowledge, this study is the first to explore the association between training volume and, pain sensitivity and endogenous analgesia in healthy competitive swimmers.

2. Methods

2.1. Study design

An observational, cross-sectional and multicenter study on baseline data was performed as part of a prospective longitudinal project aiming to define risk factors for developing shoulder pain in competitive swimmers. Baseline data were collected between September 2014 and March 2016. On field testing took place in different swimming pool areas (e.g. dressing room, first aid room) in Flanders, Belgium. The protocols were submitted to, and approved by, the Ethical Committee of Antwerp University Hospital (UZA; B300201420999). The authors declare no conflict of interest.

2.2. Participants

A total of 102 healthy competitive swimmers were recruited from five different competitive swimming clubs in Flanders, Belgium. Swimmers were included in the study if they were aged between 10 and 30 years and swam at least 4 h per week. They

competed in variable levels of competition (regional, national and/or international) and had variable stroke- and distance specialties and preferences. All participants or their legally authorized representatives received an information leaflet prior to signing the informed consent. Swimmers were excluded if they experienced shoulder pain in the last 30 days prior to onset of the study or if they suffered from any neurologic, systemic, metabolic, rheumatologic or cardiovascular disease. Swimmers with a history of major shoulder trauma, fractures of the upper limb or spine or shoulder surgery were also excluded.

2.3. Procedure

The testing procedure was performed in a swimming pool area (e.g. dressing room, first aid room), in a state of relative rest (e.g. just before the onset of a training session to avoid any influence of acute bouts of exercise). After signing the informed consent, all participants were asked to fill in a registration form. This provided the researchers with information about demographics and training routines. The latter included data regarding weekly swim- and dryland training volume (hours/week). Data were collected for pressure pain thresholds (PPTs) and conditioned pain modulation (CPM). Additionally, and in between the measurements of PPTs and CPM, measures of glenohumeral rotation range of motion and scapular kinematics were obtained in light of the longitudinal project, but will not be the topic of discussion in the present study. Three different questionnaires were used: the pain catastrophizing scale (PCS), the pain vigilance and awareness questionnaire (PVAQ), and the profile of mood States (POMS).

2.3.1. Pressure algometry

Pressure algometry, i.e. measuring PPTs, was performed by a trained physiotherapist using a calibrated digital algometer (Wagner Instruments, FDIX™; Wagner Instruments, Greenwich, CT, USA) by gradually increasing mechanical pressure perpendicularly to the test side at a rate of approximately 1 kg/s until the moment the sensation first becomes painful. Participants were instructed to say "stop" at this moment. The amount of force applied at this moment is defined as the pressure pain threshold. Because of high intrarater reliability scores (.94 - .97), these tests were performed by one single assessor on standardized spots: on the middle 1/3rd of the upper trapezius muscle belly (UT), the dorsal side of the middle phalanx of the third (middle) finger (MF) and the proximal 1/3rd of the calf muscle (CM) (Walton et al., 2011). This exact sequence was performed three times. An interstimulus interval of 5 s was applied. Since every successive stimulus was provided at another region we ruled out a temporal summation effect. The mean of the second and third measurements was used for further analysis. All PPTs were measured at the dominant side with the participant sitting on a chair and both hands on a stable surface.

2.3.2. Conditioned pain modulation

CPM uses the pain-inhibits-pain paradigm to evaluate the descending pain inhibitory function. Within this paradigm a heterotopic painful conditioning stimulus at the non-dominant upper limb was applied while re-assessing the PPTs. As with PPT testing, the assessment of CPM was also performed by one assessor and with the participant seated on a chair. An inflatable cuff was inflated at the non-dominant upper arm until the participant described a pain sensation. At this point, the pressure of the cuff was kept stable for 30 s. Afterwards the participant was asked to describe the pain on a numeric pain rating scale (NPRS) scaling 0 (= no pain at all) to 10 (= worst pain imaginable). If a NPRS score higher than 3/10 was indicated, the cuff-pressure was lowered until the subject marked the pain as a 3/10 NPRS score. The exact amount

of pressure when the participant indicated a NPRS score of 3/10 was maintained during re-assessment of the PPTs as described above and in the exact same sequence. This protocol was based on the protocol that was described and marked as reliable by Cathcart et al. (Cathcart, Winefield, Rolan, & Lushington, 2009). They demonstrated that a 3/10 CS pain intensity using an occlusion cuff resulted in reduced pain ratings to repeated mechanical stimuli. Considering the existing evidence it appears that a minimum of 3/10 pain elicited by an occlusal cuff CS is required to significantly increase CPM magnitude (Smith & Pedler, 2018). CPM measures are represented in absolute numbers and relative to the PPT and following the recommendations described by Yarnitsky et al. (Yarnitsky et al., 2010, 2015). Negative values for CPM indicate an augmentation of the PPTs while exposed to a heterotopic painful conditioning stimulus.

2.3.3. Questionnaires

All swimmers were asked to complete three questionnaires related to their psychological state and previous painful experiences. For practical reasons swimmers completed these questionnaire at a self-selected moment. The Pain Catastrophizing Scale (PCS) asks participants to reflect on past painful experiences and to indicate on a 5-point scale from 0 (not at all) to 4 (all the time), the degree to which they have experienced each of 13 thoughts or feelings when experiencing pain. The PCS is divided into 3 components all related to catastrophizing of pain (rumination, magnification and helplessness) and a total score is computed as a summation of the 3 components. The Pain Vigilance and Awareness Questionnaire (PVAQ) is a 16-item questionnaire (rated on a 6-point scale) used to investigate the attention to pain during a period in which clear pain sensations were present. It is used to assess awareness, consciousness, vigilance and observation of pain (Roelofs, Peters, McCracken, & Vlaeyen, 2003). Finally, the Short Form of the Profile Of Mood States (POMS-SF) was used to assess any form of psychological distress or mood disturbances. The POMS-SF consists of a list of 32 adjectives (rated on a 5-point scale) and provides an overall score of total mood disturbance. The POMS-SF is a self-reported assessment of mood consisting of five sub-scales: fatigue, vigor, tension, depression and anger (Curran, Andrykowski, & Studts, 1995). The results of the questionnaires were excluded once a certain questionnaire missed any data.

2.4. Data analysis

All analyses were conducted using IBM SPSS Statistics 23.0 software. First, the acquired data was prepared for analysis. Three main statistical procedures were performed: descriptive statistics, correlation analyses and linear regression. Normality of the variables was tested using the Shapiro-Wilk test and through visual inspection of the QQ-plots. Due to non-normal distributions in selected variables (dryland training volume, PPT at upper trapezius and calf muscle, and all relative CPM values) a transformation (logarithmic or square-root) of those variables was performed and normality was achieved prior to further statistical testing. To analyze the CPM effect, paired t-tests were used to compare baseline PPTs with PPTs when a conditioning stimulus was applied. Pearson correlation coefficients (r) were calculated to explore associations of selected variables. Finally, simple linear regression analysis was performed based on the outcome of our correlation analyses to determine whether training volume could account for the variance in pain-related measures in healthy competitive swimmers. Both the assumption of homoscedasticity and linearity between outcome and predictor variables have been assessed visually by plotting the standardized residuals against the predicted values.

3. Results

3.1. Descriptive statistics

Descriptive statistics are presented in Table 1 as means and standard deviations for continuous variables, and absolute frequencies for categorical variables. Age ($15.5y \pm 2.7$) varied between 10 and 25 years and swim training volumes between 4 and 22 h per week ($11.6h \pm 4.6$) were reported. One participant became unwell during the CPM procedure and these data were not used in further analyses as we had to stop the test. Results from the questionnaires are also summarized in Table 1. Due to incomplete responses on the questionnaires, the number of people analyzed is slightly lower.

Table 2 shows our results on the pain related measures. Baseline PPTs without conditioning stimulus were presented as well as the PPTs that were measured when the conditioning stimulus was applied. The latter was significantly higher ($p < .05$) for all tested regions when compared to the baseline PPTs indicating a true effect of CPM. Absolute and relative values for CPM were presented following the recommendations described by Yarnitsky et al. (Yarnitsky et al., 2010, 2015) All tested body regions showed negative mean relative CPM values indicating an augmentation of the PPTs while exposed to a heterotopic painful conditioning stimulus.

3.2. Association between swim training volume and pain-related measures

To determine the association between self-reported swim training volume and pain-related measures using static (PPTs) and dynamic (CPM) measures of pain Pearson correlation coefficients were calculated. The results of this correlation analysis are presented in Table 3. These results show moderate but statistically significant positive associations between self-reported swim training volume and PPTs. Those swimmers who were exposed to higher swim training volumes showed higher PPTs at all selected body areas. Those who participate less showed lower PPTs. No statistically significant correlations were found between swim training volume and both relative and absolute CPM. Fig. 1 graphically displays the associations between swim training volume and PPTs and CPM.

3.3. Regression analyses

Simple linear regression without selected covariates (self-

Table 1
Descriptive statistics of the study participants.

	Variable	n	
Demographics	Age (years)	101	15.5 (2.7)
	Gender (M/F)	102	54/48
Sports Specific Info	Swim Training (Hrs/Wk)	102	11.6 (4.6)
	Dryland Training (Hrs/Wk)	102	2.3 (2.1)
Questionnaires	PCS Total	87	15.4 (7.62)
	PCS (Rumination)	87	6.3 (3.31)
	PCS (Magnification)	87	3.3 (2.13)
	PCS (Helplessness)	87	5.7 (3.84)
	PVAQ Total	90	35.1 (9.74)
	POMS		
	POMS Tension	88	3.9 (4.0)
	POMS Depression	88	2.4 (3.7)
	POMS Anger	88	3.4 (3.7)
POMS Vigor	88	11.5 (4.0)	
POMS Fatigue	88	4.6 (3.8)	

n: Number of participants, M: Male, F: Female, Hrs/Wk: Hours per Week, PCS: Pain Catastrophizing Scale, PVAQ: Pain Vigilance and Awareness Questionnaire, POMS: Profile of Mood States. Values are presented as means and standard deviations for continuous variables, and absolute frequencies for categorical variables.

Table 2

Pressure pain threshold (PPT) & conditioned pain modulation (CPM).

	Upper Trapezius	Middle Finger	Calf Muscle
Pressure Pain Thresholds (N) without CS (n = 102)	35.2 (17.4)	89.8 (28.1)	53.1 (21.7)
Pressure Pain Threshold (N) with CS (n = 101)	39.35 (19.07)**	96.58 (28.37)*	58.59 (21.56)*
Absolute CPM (N) (n = 101)	-4.01 (8.66)	-6.52 (13.31)	-5.27 (11.14)
Relative CPM (%) (n = 101)	-14.33 (24.58)	-10.14 (21.17)	-14.40 (25.30)

N: Newton, n: Number of participants, PPT: Pressure Pain Threshold, CPM: Conditioned Pain Modulation, CS: Conditioning Stimulus, *p < 0.05, **p < 0.01.

Values are presented as means and standard deviations for continuous variables.

Negative values for CPM (absolute and relative) indicate pain inhibition as a result of a conditioning stimulus. In accordance to Yarnitsky et al., 2015.

Table 3

Association between swim training volume and pressure pain thresholds (PPTs) and conditioned pain modulation (CPM).

		Upper Trapezius	Middle Finger	Calf Muscle
Pearson Correlation (r) with Swim Training Volume	PPT	.38**	.42**	.42**
	CPM	-.08	-.03	-.06

r: Pearson correlation, PPT: pressure pain threshold, CPM: conditioned pain modulation, **p < .01.

reported dryland training volume, age, selected psychological factors) showed that self-reported swim training volume is a statistically significant predictor for measurements of the pressure pain thresholds at the upper trapezius muscle belly, at the middle finger and at the calf muscle ($PPT_{log10} UT (R^2 = .15, \beta = .38, p = .000)$, $PPT_{log10} MF (R^2 = .18, \beta = .42, p = .000)$, and $PPT_{log10} CM (R^2 = .17, \beta = .42, p = .000)$). When dryland training volume (*square root transformed*) was added as a covariate, these results remained statistically significant at the upper trapezius and the middle finger ($PPT_{log10} UT (R^2 = .15, \beta = .44, p = .004)$ and $PPT_{log10} MF (R^2 = .18, \beta = .47, p = .002)$), but showed a slight decrease in statistical significance at the calf muscle ($PPT_{log10} CM (R^2 = .18, \beta = .35, p = .018)$). Adding age as a covariate resulted in a decreased statistical significance at the upper trapezius ($PPT_{log10} UT (R^2 = .24, \beta = .16, p = .12)$), but did not change the results for the other regions ($PPT_{log10} MF (R^2 = .22, \beta = .28, p = .009)$ and $PPT_{log10} CM (R^2 = .20, \beta = .29, p = .008)$). Furthermore, these effects of self-reported swim training volume on pain related measurements remained statistically significant when adding selected psychosocial variables, e.g. PCS ($PPT_{log10} UT: R^2 = .11, \beta = .32, p = .002$; $PPT_{log10} MF: R^2 = .14, \beta = .38, p = .000$; $PPT_{log10} CM: R^2 = .18, \beta = .41, p = .000$) and PVAQ_{log10} ($PPT_{log10} UT: R^2 = .17, \beta = .41, p = .000$; $PPT_{log10} MF: R^2 = .20, \beta = .43, p = .000$; $PPT_{log10} CM: R^2 = .22, \beta = .44, p = .000$), as covariates.

4. Discussion

This study was the first to investigate the association of training volume and, pain sensitivity and endogenous analgesia capacity in a group of competitive swimmers. Self-reported swim training volume is associated with PPTs measured at widespread body areas. Those exposed to higher training loads showed higher PPTs, indicating lower pain sensitivity and vice versa, even after controlling for possible confounding factors such as age, dryland training volume and selected psychological factors. No associations were found between training volume and the results of CPM as a measure of endogenous analgesia capacity.

4.1. Training volume and static measures of pain

To the best of our knowledge, studies exploring possible associations between training volume and pain are currently sparse. Flood et al. (Flood, Waddington, Thompson, & Cathcart, 2017) described non-significant associations between training volume and pressure pain thresholds in a group of athletes participating in diverse types of sports activities. This diversity in included type of

sports and training variables can possibly interact with the pain related outcome measures and therefore explain the differences with our results.

Since our research question is closely related to the studies concerning long-term adaptations of pain-related measures in athletes it is worth exploring differences between athletes and non-athletes. Static psychophysical tests such as pain thresholds and pain tolerance, both measured using a variety of experimental nociceptive stimuli, were applied in athletes and non-athletes. As early as in 1981 Scott and Gijbbers concluded that national level swimmers showed significantly higher pain tolerances using ischemic pain when compared to club-swimmers and non-competitive athletes (Scott & Gijbbers, 1981). This finding is supported by studies in various types of sports, using various painful stimuli (Tesarz et al., 2012a, 2012b). Vast conclusions on causality can however not be drawn at this moment given the lack of qualitative longitudinal research within this topic. One longitudinal exploration of pain tolerance in athletes performing contact sports concluded that commitment to high contact sports throughout a whole season is linked to maintained or increased experimental pain tolerance using both a cold pressor (temperature) and a sphygmomanometer (ischemia) (Thornton, Sheffield, & Baird, 2017). Apart from these results no studies exist in which the effect of a training period on pain-related measures was directly evaluated in athletes. With respect to pain thresholds, the current literature comparing athletes with non-athletes is rather conflicting (Tesarz et al., 2012a, 2012b). If at all possible, the exact amount of training load needed to impact PPTs is currently unknown and might be influenced by factors such as type, volume and intensity of sports participation. This could possibly explain the conflicts in current evidence.

4.2. Training volume and dynamic measures of pain

We have used conditioned pain modulation and thereby the pain-inhibits-pain paradigm to evaluate the descending pain inhibitory function as a dynamic measure of pain. Our results show a statistically significant decrease in mechanical pain sensitivity using an occlusion cuff as a conditioning stimulus eliciting a pain rating of 3/10 on the NPRS. We can therefore state that a true CPM effect was induced and that the magnitude of this effect is in line with previous research using cuff occlusion and indicating an increase of PPTs anywhere from 10 to 38% (Smith & Pedler, 2018).

The majority of studies examining differences in endogenous analgesia capacity between athletes and non-athletes concluded

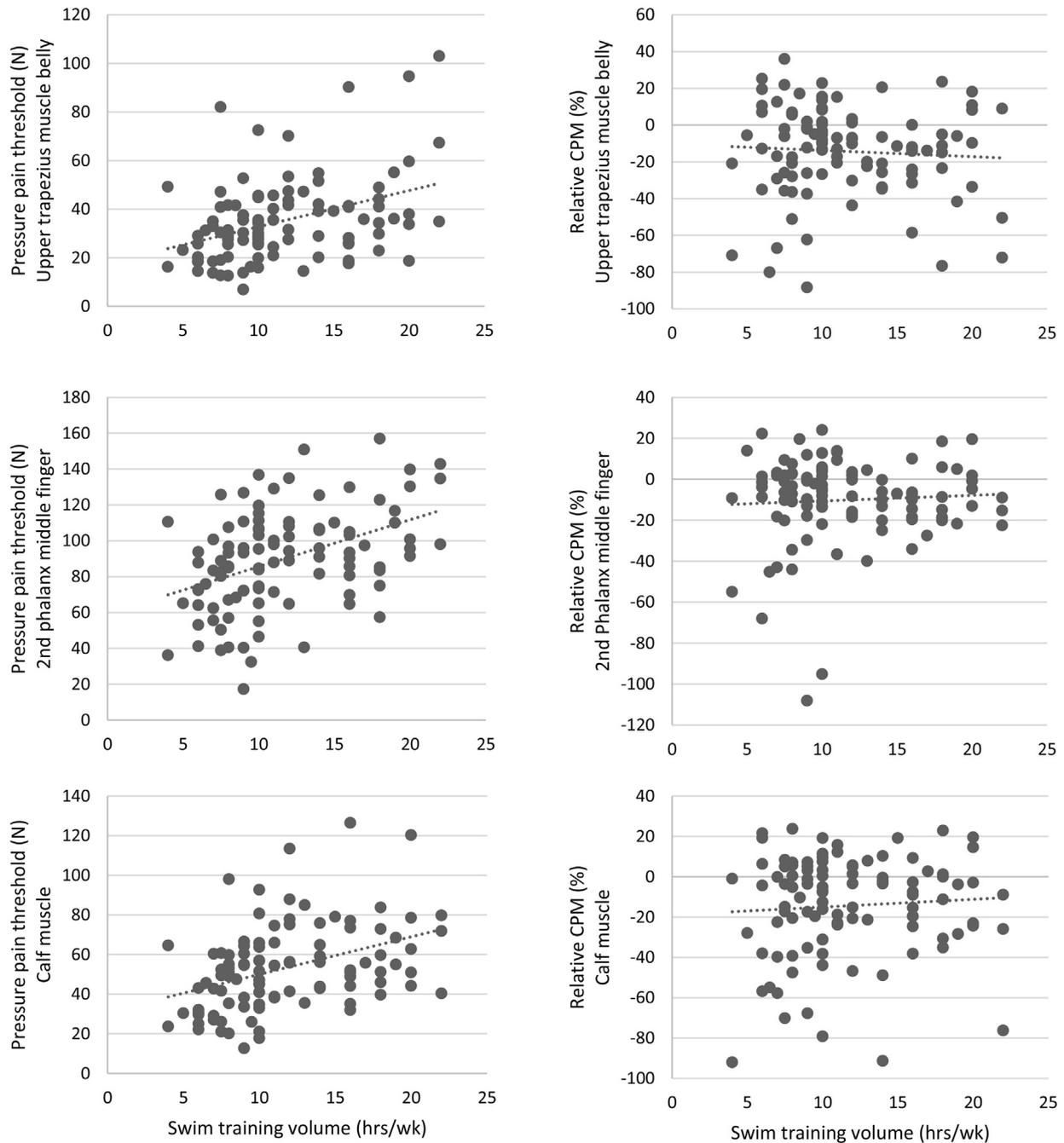


Fig. 1. Associations of swim training volume and pressure pain threshold (PPTs) and conditioned pain modulation (CPM).

that athletes showed better endogenous analgesia capacity (Flood et al., 2017; Geva & Defrin, 2013). Only Tesarz et al. (Tesarz, Gerhardt, Schommer, Treede, & Eich, 2013) concluded that athletes have a reduced endogenous pain inhibitory capacity. They have however only included endurance athletes active in regional clubs, possibly implying a less vigorous or less voluminous training regimen. This could possibly explain the discrepancy with other studies since it is known that greater levels of vigorous physical activity seem to facilitate endogenous analgesia capacity (Naugle & Riley, 2014; Umeda et al., 2016). Flood et al. even suggested a non-linear or inverted U-shaped relationship between physical activity and pain inhibition (Flood et al., 2017).

Our study did not show significant associations between self-reported training volume and measures of CPM. This apparent discrepancy with the previously mentioned studies in athletes versus non-athletes might find different possible explanations. It has been shown that the magnitude of the CPM effect is dependent on the intensity of the conditioning stimulus (Smith & Pedler, 2018). Since we have used a rather low intensity as a conditioning stimulus we cannot be sure that the CPM, however being significant, was maximally evoked. The differences in used modalities might also explain different findings in different studies, e.g. Geva et al. found superior pain modulation in athletes using thermal stimuli (Geva & Defrin, 2013). Furthermore the timing of

stimulation might create discrepancies. Flood et al. used a sequential timing protocol (test-stimulus after conditioning stimulus) whereas we have used a parallel timing protocol (test-stimulus together with conditioning stimulus) (Flood et al., 2017). The latter might even overestimate the CPM effect as a result of a shift in attention (Yarnitsky et al., 2015). Eventually pain inhibitory capacity might also be an innate capability that predisposes one to be an athlete and thus is less affected by training or exercise.

4.3. Study strengths and limitations

Cautiousness is warranted when generalizing the results of this study and applying them to other types of sports. Swimming is a unique and popular sport among all generations combining sport specific characteristics such as endurance, strength and movement control training in a non-weight bearing environment (Struyf, Tate, Kuppens, Feijen, & Michener, 2017). The non-weight bearing effect of water reduces the risk of injury at recreational level and improves general health (Gaunt & Maffulli, 2012). In contrast, research in competitive swimmers has shown prevalence rates of shoulder pain varying from 40 to 91% (Sein et al., 2010; Tate et al., 2012; Wanivenhaus, Fox, Chaudhury, & Rodeo, 2012). Clearly pain is omnipresent in competitive swimming. Competitive swimmers believe pain during swimming practice is normal and should be tolerated (Hibberd & Myers, 2013). Since cognition determines behavior this finding possibly interferes with our results and therefore may limit the generalizability.

Furthermore, some limitations must be considered when interpreting the presented results. Information on both swim- and dryland training volume was obtained using a self-reported registration form, thereby risking response bias. Other measures of training volume (e.g. total swim distance) as well as measures of training intensity (e.g. session RPE (rating of perceived exertion)) should be considered in subsequent research (Herman, Foster, Maher, Mikat, & Porcari, 2006). Another limitation of this study is the possible inconsistency in time of reporting on the provided questionnaires that may have impacted the responses. Also, despite existing evidence on differences in pain tolerance between athletes and non-athletes, we did not measure pain tolerances in this study. Information on possible associations between training volume and pain tolerance would be of added value in this discussion. A possible study limitation could also arise from the methodology of PPT assessment as its reliability is subjected to experimenter bias. However, in order to optimize the reliability and minimize experimenter bias, the PPTs of all participants were measured three times by one trained assessor with 12 years of experience. Another strong methodological characteristic lies in the use of regression analyses taking into account confounding factors, such as age and selected psychological factors, known to possibly interfere with pain-related outcome measures (El Tumi et al., 2017; Lautenbacher et al., 2017; Lumley et al., 2011; Patanwala et al., 2018; Persad et al., 2017; Sheffield et al., 2000; Vranceanu et al., 2009). Cautiousness is however needed as self-reported swim training volume (even when combined with age, dryland training and psychosocial factors) only accounts for about 20% of the variance in PPTs. This means that other factors need to be addressed when aiming to more strongly predict outcomes of pressure algometry.

4.4. Practical applications

Some practical and research implications result from this study. Experimental pain could be influenced by swim training volume. Indeed, swimmers who train more show higher pressure pain thresholds, indicating lower pain sensitivity and a possible training induced hypoalgesia. More longitudinal research providing info on

causality is clearly warranted. Training induced hypoalgesia could account for performance enhancement similarly as those induced using analgesic substances such as acetaminophen (Foster, Taylor, Chrismas, Watkins, & Mauger, 2014; Mauger et al., 2014). More research on training induced hypoalgesia and its possible influences on performance is necessary.

5. Conclusions

We conclude that swim training load is associated with pain sensitivity in competitive swimmers. Those who train more show consistently higher pressure pain thresholds at widespread body parts. No associations were found between training load and measures of endogenous pain inhibition.

Declarations of interest

None.

Ethical approval

The protocols were submitted to, and approved by, the Ethical Committee of Antwerp University Hospital (UZA; B300201420999). All subjects or their legally authorized representatives received an information leaflet prior to signing the informed consent. Volunteers' names and/or initials have not been used.

Conflict of interest

None.

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Nothing to declare.

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