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Review Article

The relationship between training load and pain, injury and illness in competitive swimming: A systematic review

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A B S T R A C T

Background: Research suggests that the frequency of training, combined with the repetitive motion involved in high volume swimming can predispose swimmers to symptoms of over-training. The prevention of pain, injury and illness is of paramount importance in competitive swimming in order to maximise a swimmer's ability to train and perform consistently. A significant factor in the prevention of pain, injury or illness is the appropriate load monitoring and management practices within a training programme.
Objective: The purpose of this systematic review is to investigate the relationship between training load and pain, injury and illness in competitive swimmers.
Methods: The databases SPORTDiscus, CINAHL, Scopus, MEDLINE and Embase were searched in accordance with PRISMA guidelines. Studies were included if they reported on competitive swimmers and analysed the link between training load and either pain, injury or illness. The methodological quality and study bias were assessed using the Joanna Briggs Institute Critical Appraisal Checklist.
Results: The search retrieved 1,959 articles, 15 of which were included for review. The critical appraisal process indicated study quality was poor overall. Pain was the most explored condition (N = 12), with injury (N = 2) and illness (N = 1) making up the remaining articles. There was no evidence of an association between training load and pain, while there may be some evidence to suggest a relationship between training load and injury or illness.
Conclusions: The relationship between training load and pain, injury or illness is unclear owing to a host of methodological constraints. The review highlighted that youth, masters and competitive swimmers of a lower ability (e.g. club versus international) may need particular consideration when planning training loads. Winter periods, higher intensity sessions and speed elements may also need to be programmed with care. Monitoring practices need to be developed in conjunction with consensus guidelines, with the inclusion of internal training loads being a priority. Future research should focus on longitudinal prospective studies, utilising the session Rating of Perceived Exertion (sRPE) monitoring method and investigating the applicability of Acute/Chronic Workload Ratio (ACWR) and exponentially weighted moving average (EWMA). Improved methods and study design will provide further clarity on the relationship between load and pain, injury, and illness.

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1. Background

Aquatic sports were one of the original sports in the modern Olympic Games, and have since grown to have the second-highest athlete participation, with 900 competitive swimmers participating at the 2016 Rio Olympic Games (Rio, 2016). In competitive swimmers, injury prevalence ranges from 32.2% to 74.6%, with the shoulder accounting for a large proportion of injuries, followed by knee and lower back injuries (Toomey, Richmond, & Black, 2018). The incidence of overuse injuries (1.48) surpasses that of acute

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injuries (1.10) when adjusted per 1000 exposure hours in competitive swimmers (Ristolainen et al., 2010). Despite 81% of Olympic swimming events being contested in under 2 min and 20 s, the traditional training practices of competitive swimmers are high in volume (Nugent, Comyns, Nevill, & Warrington, 2019). The extensive nature of training means there is a significantly higher incidence of injury in training than in competition (Soligard et al., 2017). An abundance of research suggests that the high frequency of training (Weldon & Richardson, 2001), as well as the repetitive motion (Pink & Tibone, 2000), can predispose swimmers to symptoms of overtraining (Khodaee et al., 2016). Overtraining is defined as the accumulation of training or non-training stress resulting in a long term decrement in performance capacity (Lehmann, Foster, Gastmann, Keizer, & Steinacker, 1999). Overtraining can often have related physiological signs and symptoms of prolonged maladaptation (Meeusen et al., 2006), leading to disturbances in the endocrine, immune, musculoskeletal and neurologic systems (Myrick, 2015).

Prevention of pain, injury and illness is of paramount importance within elite sport, not only to safeguard the long-term health of the athlete but to maximise their ability to train and perform without interruption (Palmer-Green, Fuller, Jaques, & Hunter, 2013). Finding a balance between training load and recovery is crucial in the prevention of overtraining (Kenttä & Hassmén, 1998). To this end, the dose-response relationship needs to be monitored. While the response aspect of this paradigm is more easily measured, the dose imposes more logistical challenges (Lambert & Borresen, 2010). The incidence of injury in swimming is seen as being low in comparison to other sports, but the prevalence of overuse injuries is high (Matsuura et al., 2019). This further emphasises the importance of load monitoring among elite swimmers (Pollock et al., 2019), and also the quantification of the training load in order to identify the effects of training (Mujika, 2017). Training load can be divided into internal and external loads, with external loads describing the quantification of work and internal loads describing the response to that work (Drew & Finch, 2016). In swimming, distance, time or speed are habitually used to monitor the external training load, with heart rate typically used to monitor internal training load (García-Ramos et al., 2015). A range of other methods such as self-administered questionnaires, sport-specific performance tests and blood screening have been used as methods to reduce the risk of overtraining (Pollock et al., 2019).

The links between various measures of training load and either pain, injury or illness have been examined across a variety of sports (Eckard, Padua, Hearn, Pexa, & Frank, 2018; Johnston et al., 2019; Jones, Griffiths, & Mellalieu, 2017). While training load, pain, injury and illness have become key terms within sport science, a lack of consistency in their definitions has also arisen (Jones et al., 2017). The rise to prominence of training load monitoring (Newton, Owen, & Baker, 2019) and injury surveillance (Palmer-Green et al., 2013) practices over the past decade has seen a subsequent increase in the need for consensus statements. Sports such as cricket, football, rugby union, rugby league, tennis, athletics and horse racing have all published epidemiological consensus statements in recent years (Bahr et al., 2020). Many of these statements attempt to improve consistency in reporting guidelines to enable the comparison of methodologies and findings. A consensus statement from Fédération Internationale de Natation (FINA) in 2016 (Mountjoy et al., 2016), provided clarity on the reporting of injuries and illness in aquatic sports, but neglected to address the monitoring of training load within the sport and its links with injury surveillance. In the same year, Drew and Finch (Drew & Finch, 2016) published a systematic review investigating the relationship between training load, and injury, illness and soreness in a broad range of sports. The review categorised injury and illness into medical attention and time loss definitions, while it also expanded into the area of overuse injuries. The term soreness in this review was identified as the prevalence of symptoms irrespective of medical attention or time loss. Including this term broadened the reviews focus to papers that may incorporate ‘athlete’s self-reported injury’ (soreness or pain) as recommended by the Injury Definitions Concept Framework (Drew & Finch, 2016; Timpka et al., 2015). The review concluded that there is moderate evidence of a relationship between training and competition load and the incidence of injury, illness and soreness. Their findings highlighted that training load should be monitored, using session Rating of Perceived Exertion (sRPE) to avoid acute spikes in load (Drew & Finch, 2016). This review included 35 studies; however, only one swimming paper met the inclusion criteria. More recently, a systematic review completed by Feijen et al. (Feijen, Tate, Kuppens, Claes, & Struyf, 2020) investigated the link between swim training volume and shoulder pain. The review encompassed 12 studies and highlighted that swim training volume was associated with shoulder pain in adolescent competitive swimmers. While the review provided worthwhile information, several limitations were acknowledged. The review solely focused on measures of external training load (i.e. volume) and limited the scope to shoulder pain. The International Olympic Committee (IOC) consensus statements on load in sport and risk of injury (Soligard et al., 2016), and risk of illness (Schwellnus et al., 2016) have stated injury aetiology is multifactorial and that load monitoring needs to include a combination of both external and internal loads.

To date, no review has completed a comprehensive assessment of the relationship between internal and external training load and pain, injury, or illness in competitive swimming. This review aims to provide a clear consensus for practitioners working within competitive swimming on the relationship between training load and pain, injury, and illness. Using the most recent guidelines on training load and injury/illness surveillance, it is intended to close a gap within the literature in competitive swimming as other sports have done in recent years. Consequently, the purpose of this systematic review is to determine if a relationship exists between training load and pain, injury and illness in competitive swimmers.

2. Methods

2.1. Literature search

The search strategy followed the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) Guidelines (PRISMA-P GroupMoher et al., 2015). The keyword search string included combinations of the following: Training Load, Swimming, Competitive, Injury, Pain, Illness. Each keyword was broken into its individual Medical Subject Headings (MeSH), terms or synonyms and joined where appropriate by Bolan terms “AND”/“OR”. A copy of the keyword search string is provided in theelectronic supplementary material. Relevant studies were then identified through running the keyword string through five targeted databases: SPORTDiscus, CINAHL, Scopus, MEDLINE and Embase.

2.2. Selection criteria

Once the search was conducted, results were filtered for English language within each database. No date limits were applied. Remaining results were then stored on a reference management tool (Zotero.org) for manual screening. Using the reference management tool, duplicates were removed, and titles were initially screened for relevance to the subject matter by a single reviewer (LB). Articles clearly outside the scope of this review were excluded. Titles and abstracts were then screened for the inclusion criteria by two reviewers (LB, TC). Articles were segregated into "YES", "NO", "MAYBE" folders according to their eligibility.

The following inclusion criteria had to be present in order for the study to be considered: 1) the study had to be printed in the English language in a peer-reviewed journal and excluded case study, case series, reviews, interventions, conference proceedings; 2) the method of the study had to clarify that participants were competitive swimmers; 3) one or more measures of internal or external training load had to be reported; 4) an outcome measure of pain, injury or illness had to be reported, which could be self-reported or diagnosed by a health professional; and 5) a statistical analysis of the difference or association between training load and pain, injury or illness had to be reported.

Full-text copies of both the "YES" and "MAYBE" articles were sourced and rescreened for inclusion. A comparison of both reviewers' results was made with a third independent reviewer (ML) acting as an adjudicator in the event of a disagreement. Once consensus was reached, a full search for additional papers of the final articles reference lists was carried out. Any articles sourced through secondary means (e.g. reference list search, etc.), were screened by both reviewers and included where appropriate. Fig. 1 presents a flow chart diagram of the systematic search process.

2.3. Data extraction

Key information pertaining to the inclusion criteria were extracted from each study, using a standard data collection form. Study design, population characteristics (i.e. number of participants, level of ability, sex and age), training load measured (internal or external), outcome (measure of pain, injury, illness), method of collection for both training load and outcome, definition of outcome used, key results or findings were extracted. If any key information was not available, the corresponding author was contacted. If no response was received after a period of six weeks, the information was deemed unavailable. Findings included those that tested for significant difference (p-values between groups) as well as those that tested for an association (Odds Ratios between exposure and outcome). The data extraction table was cross-checked for accuracy by a second reviewer (TC). Studies were grouped by outcome for comparison purposes (see Table 1).

2.4. Training load measures

Internal and external training load measures were defined and extracted based on Eckard et al. (Eckard et al., 2018). Internal training load was defined as the athlete's response to an external stimulus (e.g. RPE, heart rate (HR), etc.). External training load was defined as any external stimulus applied to the athlete independent of their athlete characteristics (e.g. distance, time, etc.) (Eckard et al., 2018). Method of collection was designated as either being self-reported (SR) when the athlete themselves recorded the load, or "third party" when the load data were collected and reported by a designated person within the coaching or research team.

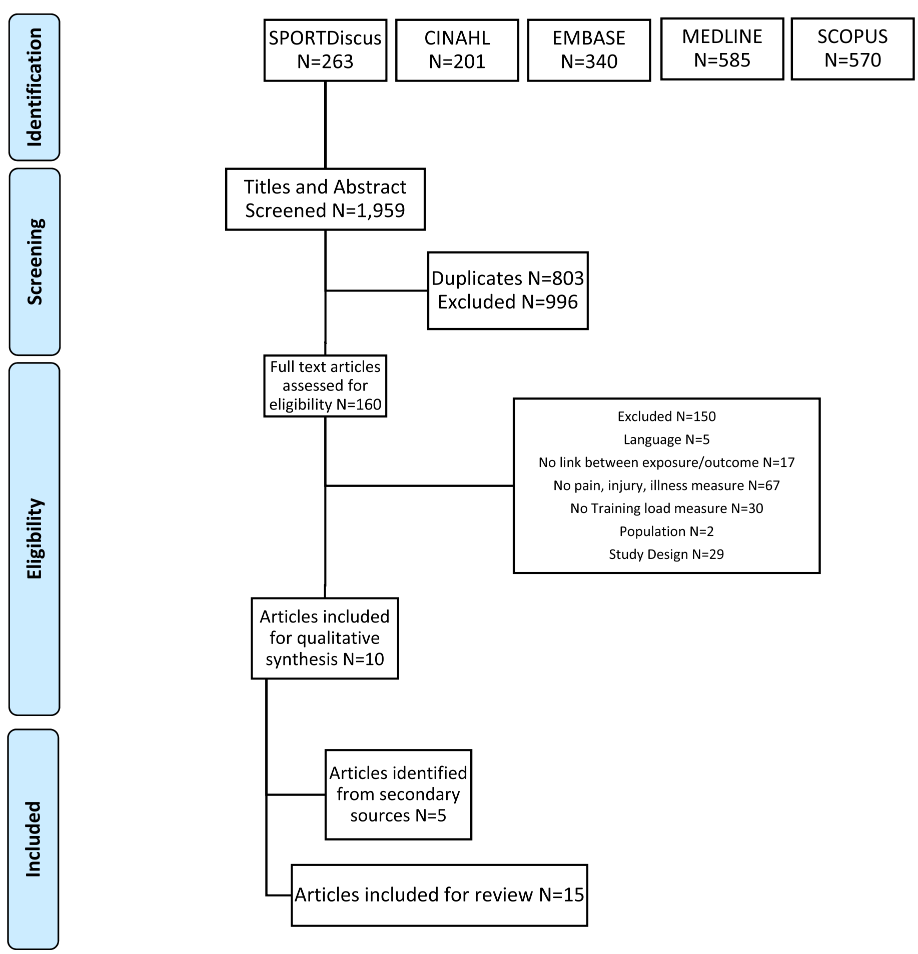

Fig. 1. Preferred Reporting Items for Systematic Review flow diagram representing the systematic search process.

Table 1
Summary of the included studies.

Reference(Study Design)	Population(N, gender, age)	Level of Competitiveness	Load	Method of Collection	Outcome(Definition)	Findings
Martins et al. (Martins et al., 2018) Cross-Sectional	42 Elite Swimmers 22M 20F Mean Age 22.9 (±4.4) yrs.	Swam average of 45.2 (±20) km/wk. Competitive for 13.9(±6.9) years.	External: km/wk.	Load: SR. Outcome: SR.	Pain NR.	km/wk did not have any significant statistical association with the occurrence of pain ($p = 0.79$)
Tessaro et al. (Tessaro et al., 2017) Cohort 12 months Retrospective	197 Club Swimmers 108M 89F Mean Age: 14.01 (±2.12) yrs.	Swim average of 25.31 (±9.02) km/wk.	External: freq/wk hr/session km/session.	Load: SR/Third Party. Outcome: SR.	Pain NR.	No statistically significant differences were found between pain and freq/wk ($p = 0.11$), hr/session ($p = 0.16$), km/wk ($p = 0.31$).
Krüger et al. (Krüger et al., 2012) Cohort 3 years Retrospective	282 Masters Swimmers 138M 144F Mean age: Male 50 yrs ; Female 49 yrs .	Participants at South African Masters Swimming Championship.	External: m/wk low (0–4,999) medium (5,000–11,999) high (>12,000).	Load: SR. Outcome: SR.	Pain NR.	Low/medium training volume (OR 1.0) High Volume (OR 0.36, 95% CI 0.568–0.680; $p = 0.004$)
Harrington et al. (Harrington et al., 2014) Cross-Sectional	37 Collegiate Swimmers 37F Mean Age = 19.5 (±1.19) yrs.	NCAA Division I swim programs. Swimming 18.8 h/wk.	External: hr/wk practices/wk.	Load: SR. Outcome: SR.	Pain DASH(>6/20 points) PSS(>4/10).	No significant difference was found in the hr/wk for the dominant ($p = 0.77$) or non-dominant arm ($p = 0.97$) in relation to the presence of shoulder pain.
Walker et al. (Walker et al., 2012) Prospective Cohort 12 months	74 Club Swimmers 37M 37F Mean Age: 15 (±3) yrs.	Swimming 8 (±2) sessions/wk. Average distance of 44 (±15) km/wk.	External: km/wkpractices/wk.	Load: Third Party. Outcome: SR.	Pain/Injury NTL/TL SIP SSI.	Swim training distance (km) was not a significant predictor of: SSI (OR, 1.0; 95%CI,1.0,1.0), ($p = 0.11$). SIP (OR, 1.0; 95%CI,1.0,1.0), ($p = 0.07$).
de Almeida et al. (de Almeida et al., 2015) Cross-Sectional	257 National Swimmers 140 M 117 F Mean age: Male 20.6 (±3.7); Female 19.4 (±3.9) yrs.	Weekly distance 57.1 (±29.9) km/wk.	External: km/wk.	Load: SR. Outcome: SR.	Pain/Injury MA/TL.	No significant difference found for weekly distance in km ($p = 0.61$) when those with and without pain were compared.
Tate et al. (Tate et al., 2012) Cross-Sectional	42 Youth Swimmers 42F Age: 8–11 yrs.	Swimming 6.9 (±2.4) hr/wk.	External: hr/wk.	Load: SR. Outcome: SR.	Pain PSS(>2/10).	There were no significant differences in: Time swam (yrs) ($p = 0.74$) Time swam/wk (hr) ($p = 0.18$) Time swam/yr (hrs) ($p = 0.54$)
	43 Youth Swimmers 42F Age:12–14 yrs.	Swimming 10.1 (±4.3) hr/wk.			DASH(>6/20) PSS(>4/10).	There were no significant differences in: Time swam (yrs) ($p = 0.29$) Time swam/wk (hr) ($p = 0.56$) Time swam/yr (hrs) ($p = 0.69$)
	84 High-School Swimmers 84F Age:15–19 yrs.	Swimming 16.1 (±6.0) hr/wk.				There were no significant differences in: Time swam (yrs) ($p = 0.01$) Time swam/wk (hr) ($p = 0.71$) Time swam/yr (hrs) ($p = 0.60$)
	67Masters Swimmers. 67F	Swimming 4.0 (±1.7) hr/wk.				There were no significant differences in: Time swam (yrs) ($p = 0.13$) Time swam/wk (hr) ($p = 0.06$) Time swam/yr (hrs) ($p = 0.02$)
Capaci et al. (Capaci et al., 2002) Cross-Sectional	38Club Swimmers 38M Mean age: 14.44 (±2.4) yrs.	Average training hr/wk: 8.52 (±1.54).	External: Average training hr/wk.	Load: SR. Outcome: SR.	Pain NTL/TL Classified into categories (1–5).	Swimmers with pain swam 8.86 (±1.25) hr/wk which was significantly different to swimmers without pain who swam 8.00 (±1.06) hr/wk.
Su et al. (Su et al., 2004) Cross-Sectional	40 Club Swimmers. 19M 21F Age 18-35 yrs.	Competitive experience >5years. Training Schedule >2 days and 10 km/wk.	External: hr/wk km/session.	Load: SR. Outcome: SR/CA.	Pain NTL/CA Phase II or III - Neer and Welsh swimmer's shoulder grading system.	There were no significant differences in practice duration($p = 0.80$) and practice distance ($p = 0.33$) between the healthy and impingement groups.
Hidalgo-Lozano et al. (Hidalgo-	54 Elite Swimmers 18M	European and World Championship participants.	External: hr/wk.	Nil	Pain Pain felt in the neck-shoulder and/or arm	No correlation between shoulder pain and hr/wk ($p = 0.73$) was found.

(continued on next page)

Table 1 (*continued*)

Reference(Study Design)	Population(N, gender, age)	Level of Competitiveness	Load	Method of Collection	Outcome(Definition)	Findings
Lozano et al., 2012) Cross-Sectional	16F Age: 18–30 yrs.	Swimming 6 h per day for 4 days per week.			>3 months. >4/10 NPRS.	
Hidalgo-Lozano et al. (Hidalgo-Lozano et al., 2013) Cross-Sectional	35 Elite Swimmers Age:18–30yrs.	Swimming >6 h/wk.	External: hr/wk.	Load: SR. Outcome: NPRS, Anatomical Chart.	Pain >3months 4/10 NPRS during arm elevation. CA + ive Neers and Hawkins test.	No correlation between shoulder pain and hours training/wk ($p = 0.13$).
Cejudo et al. (Cejudo et al., 2019) Cross-Sectional	24 Club Swimmers 15M 9F Mean age: 15.6 (±2.2) yrs.	Swimming experience of 6.8 (±2.1) yrs. Training hr/wk 15.3 (±1.7).	External: Practice frequency hr/wk.	Load: SR. Outcome: SR.	Pain NTL/TL SIP.	Training hours per week was not a distinguishing factor between those with shoulder pain and those without ($p = 0.77$, d = 0.30 small)
Tomar and Allen (Tomar & Allen, 2019) Prospective Cohort 7 Weeks	12 Collegiate Swimmers.	Mean weekly training load: 260.97 ± 56.33AU.	External: min/session. Internal: sRPE.	Load: SR. Outcome: Third Party.	Injury NTL.	No significant relationship between training load (r = −0.35), monotony (r = 0.62), strain (r = −0.12), acute/chronic workload (r = 0.08) and injury.
Ristolainen et al. (Ristolainen et al., 2014) Cohort Retrospective 12 months	154 National Swimmers 71M 83F Mean Age 18.6 (±2.9) yrs.	Finnish Top Level. Swimming exposure of 767 (±326) hr/yr. Active Training (years) 9.9 (±3.1) yrs.	External: km/yr hr/wk hr/yr.	Load: SR. Outcome: SR.	Injury Overuse injury TL/MA.	Injured swimmers had swum significantly more than non-injured swimmers during the past 12 months ($p = 0.04$) The mean number of kilometres swam was higher in swimmers with at least one joint injury compared to swimmers without such an injury ($p = 0.03$)
Hellard et al. (Hellard et al., 2015) Prospective Cohort 4 years	28 Elite Swimmers 14M 14F Age 16–30yrs.	National Championship participants. >9 sessions/wk (including dryland conditioning). High motivation in the past 6 months.	External: m/wk. Internal: Blood Lactate Profile.	Load: External - NR. Internal - Third Party. Outcome: SR.	Illness (URTPI) MA/TL.	The risk of URTPI was significantly increased with high load training (OR 1.10; 95% CI, 1.01–1.19), ($p = 0.02$). The odds of having an URTPI was 70% lower during taper (OR .30; 95% CI, 0.13–0.70), ($p = 0.005$) 50% lower during competition (OR 0.50; 95% CI, 0.23–1.06), ($p = 0.07$) than during periods of intensive training.

2.5. Operational outcome definition

The definition used for pain, injury or illness was extracted and categorised where possible according to Mountjoy et al. (Mountjoy et al., 2016) and Langhout et al. (Langhout et al., 2019). Pain, injury or illness could be categorised as "non-time loss" (NTL), "medical attention" (MA) or "time loss" (TL). Medical attention is where a qualified clinician has assessed the athlete's medical condition (Mountjoy et al., 2016), TL was defined as one which led to the athlete being unable to participate in full FINA activities (Mountjoy et al., 2016), and NTL was any physical complaint as a result of competition or training but without time-loss (Langhout et al., 2019).

2.6. Critical appraisal

The Joanna Briggs Institute (JBI) Critical Appraisal Checklists for cohort and cross-sectional studies were utilised to assess the risk of bias for each individual study as relevant to their study design (Joanna Briggs Institute, 2020). Two reviewers (LB, TC) individually critically appraised 15 studies (10 cross-sectional, 5 cohorts). Each tool included between 8 and 11 questions with a focus on the appropriateness of the study design, presence of selection bias, validity and reliability of methods, the handling of confounding factors and appropriateness of the statistical analyses used. Authors assigned a "Yes", "No", "Unclear" or "Not Applicable" to each question, depending on the perceived risk of bias. Study quality was considered poor if they had ≥3 "no" or "unclear" responses as outlined in Nour et al. (Nour, Lutze, Grech, & Allman-Farinelli, 2018). Discrepancies between the two reviewers were resolved through discussion and a third party (CP) was consulted in the event an agreement could not be reached.

3. Results

An online systematic search retrieved 1,959 articles across five databases, 803 of which were duplicates. Initial screening of titles and abstracts excluded 996 articles, leaving 160 full-text articles to be assessed. The original database search uncovered 10 articles which met the inclusion criteria, with a further 5 articles being included from secondary sources. A total of 15 articles were included for review; 5 cohort and 10 cross-sectional study designs. An outcome of pain was the most explored condition (N = 12), with injury (N = 2) and illness (N = 1) making up the remainder of the articles.

3.1. Critical appraisal

The overall study quality was poor, with ten (Capaci, Ozcaldiran, & Durmaz, 2002; de Almeida, Hespanhol Junior, & Dias Lopes, 2015; Harrington, Meisel, & Tate, 2014; Hellard, Avalos, Guimaraes, Toussaint, & Pyne, 2015; Krüger, Dressler, & Botha, 2012; Martins, Paiva, Freitas, Miguel, & Maia, 2018; Ristolainen, Kettunen, Waller, Heinonen, & Kujala, 2014; Tate et al., 2012; Tomar & Allen, 2019; Walker, Gabbe, Wajswelner, Blanch, & Bennell, 2012) of the fifteen studies scoring ≥3 in the "no" or "unclear" categories. Tessaro et al. (Tessaro, Granzotto, Poser, Plebani, & Rossi, 2017) was the only study to receive a positive appraisal in all eight categories, while Krüger et al. (Krüger et al., 2012) had the most "no" or "unclear" responses. A consistent weakness of all the studies was related to managing confounding factors. Twelve studies identified confounding factors, but only six (Capaci et al., 2002; Harrington et al., 2014; Hellard et al., 2015; Martins et al., 2018; Tate et al., 2012; Walker et al., 2012) outlined a strategy to deal with them. Strategies included excluding participants who participated in additional sports or who had a previous surgery on the area of interest. In the cross-sectional studies, all reported sufficient detail regarding the population and setting. The exposure and outcome were measured in a valid and reliable way in 27% and 67% of all studies. This highlighted that the method of monitoring exposure was a common limitation within the study design, most of which relied on self-reported questionnaires. Statistical analysis were conducted in an appropriate manner in 87% of all studies. Table 2 presents the JBI quality checklist information for each of the included studies.

3.2. Participant demographics

A total of 1510 swimmers were included in the review with 11% of them categorised as elite (Hellard et al., 2015; Hidalgo-Lozano et al., 2012, 2013; Martins et al., 2018), 36% club level (Capaci et al., 2002; Cejudo, Sánchez-Castillo, Sainz de Baranda, Gámez, & Santonja-Medina, 2019; Su, Johnson, Gracely, & Karduna, 2004; Tate et al., 2012; Tessaro et al., 2017; Walker et al., 2012), 23% masters level (Krüger et al., 2012; Tate et al., 2012), 3% collegiate (Harrington et al., 2014; Tomar & Allen, 2019) and 27% national level (de Almeida et al., 2015; Ristolainen et al., 2014). The mean age range was 8–49.5 years, with two studies not reporting age for one group or all of their participants' demographics (Tate et al., 2012; Tomar & Allen, 2019). A variety of descriptors outlining participant's level of ability, including average training distance and hours per week were recorded in the majority of circumstances. Large range training volumes in kilometres per week (25–58 km/week) or hours per week (4–24 h/week) were reported. Ten studies reported results from both male and female participants, while one study reported solely on male participants (Capaci et al., 2002) and two studies on female participants (Harrington et al., 2014; Tate et al., 2012). Two studies did not disclose the gender balance of their participants (Hidalgo-Lozano et al., 2013; Tomar & Allen, 2019).

3.3. Operational outcome definition

The definition of pain, injury and illness varied amongst the fifteen studies. Of the two injury based studies, one of the definitions required a restriction of training (Tomar & Allen, 2019), with the second specifically focused on overuse injuries, outlining a definition with elements of TL and MA criteria (Ristolainen et al., 2014). Regarding illness, the definition provided was based on Fricker et al. (Fricker et al., 2005) and required the athlete to have received MA and TL away from training. Out of the three categories of pain, injury and illness, studies investigating pain used the most diverse definitions. Three studies utilised a Numerical Pain Rating Scale (NPRS) (Hidalgo-Lozano et al., 2012, 2013; Tessaro et al., 2017) with two reporting a set threshold of 4/10 on the NPRS to denote significant pain (Hidalgo-Lozano et al., 2012, 2013). The remaining study did not provide a set threshold on the scale (Tessaro et al., 2017). Subscales from the Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire and the Penn Shoulder Score (PSS) were combined to form the Sports and Symptom Survey Form utilised in two of the studies (Harrington et al., 2014; Tate et al., 2012). A set injury definition (McMaster, Roberts, & Stoddard, 1998) was used in two studies (Cejudo et al., 2019; Walker et al., 2012) which classified significant interfering shoulder pain (SIP) as a pain that interfered with training or competition, or progression in training and caused a cessation or modification of training or racing. A 1–5 pain scale was used in one study which indicated if the participant had no pain at level 1, up to pain preventing competitive swimming at level 5 (Capaci et al., 2002). A mixed MA/TL definition was employed in one study (de Almeida et al., 2015), which referred to the consensus statement of Fuller (Fuller, 2006). A clinical assessment or screening process was conducted in two of the studies (Hidalgo-Lozano et al., 2013; Su et al., 2004) in conjunction with a set definition. Martins et al. (Martins et al., 2018) did not provide a definition of pain but highlighted that a questionnaire which evaluated the occurrence of pain was administered. Pain was present if the responder answered "yes" to a question on the presence of pain. Similarly, Krüger et al. (Krüger et al., 2012) did not provide a set definition of pain but outlined that a retrospective questionnaire was used to determine the incidence of shoulder pain over a three-year period.

3.4. Monitoring training load

All the papers included for review collected external training load, using one or more variations. Session duration was the most commonly used unit of load. Nine out of fifteen studies employed this approach and was most often recorded as hours per week. This was closely followed by session distance, which was collected in eight studies, most of which was recorded as kilometres per week. Finally, session frequency was collected in five studies with practices per week being most frequent. Two out of fifteen studies collected internal training load, with session intensity recorded through the use of sRPE (Tomar & Allen, 2019) and blood lactate concentration (Hellard et al., 2015). The method of collecting training load data was reported well in the majority of cases. However, one study (Hidalgo-Lozano et al., 2012) collected training load as hours/week but did not report the method of data collection. Another study reported how the internal training load (blood lactate profile) was collected, but not the external training load measure (meters/week) (Hellard et al., 2015). Training load data were typically collected subjectively through athlete self-reporting, generally through the use of a questionnaire. A third party was used to submit the data in two instances (Tessaro et al., 2017; Walker et al., 2012), namely the coach, clinician or research assistant.

3.5. Relationship between training load and pain, injury, and illness

Eleven of the fifteen studies stated no statistically significant differences or associations between a measurement of training load and the outcome reported (Cejudo et al., 2019; de Almeida et al., 2015; Harrington et al., 2014; Hidalgo-Lozano et al., 2012, 2013; Martins et al., 2018; Su et al., 2004; Tate et al., 2012; Tessaro et al., 2017; Tomar & Allen, 2019; Walker et al., 2012). In the remaining studies, a statistically significant difference was reported between training load and injury (Ristolainen et al., 2014) and pain (Capaci et al., 2002). A positive association was seen between training load and illness (Hellard et al., 2015), while a negative association was reported between training load and pain (Krüger et al., 2012).

Two out of twelve studies found a statistical difference or association between training load and pain (Capaci et al., 2002; Krüger et al., 2012). Both studies reported contrasting conclusions with Capaci et al. (Capaci et al., 2002) highlighting that swimmers experiencing musculoskeletal pain reported swimming significantly ($p < 0.05$) more hours per week than those without pain (8.86 ± 1.25 vs 8.00 ± 1.06 h/week). This finding contradicted Krüger et al. (Krüger et al., 2012) who suggested that those swimming lower volumes (0–4,999 m/week), were 2.8 times more likely

Table 2
– Critical Appraisal using the JBI checklist for cohort and cross-sectional studies.

Cohort	Were the two groups similar and recruited from the same population?	Were the exposures measured similarly to assign people to both exposed and unexposed groups?	Was the exposure measured in a valid and reliable way?	Were confounding factors identified?	Were strategies to deal with confounding factors stated?	Were the groups/participants free of the outcome at the start of the study (or at the moment of exposure)?	Were the outcomes measured in a valid and reliable way?	Was the follow up time reported and sufficient to be long enough for outcomes to occur?	Was follow up complete, and if not, were the reasons to loss to follow up described and explored?	Were strategies to address incomplete follow up utilised?	Was appropriate statistical analysis used?
Tomar and Allen (Tomar & Allen, 2019)	Y	NA	Y	N	N	UC	Y	N	UC	UC	Y
Walker et al. (Walker et al., 2012)	N	NA	N	Y	N	Y	Y	Y	Y	Y	Y
Hellard et al. (Hellard et al., 2015)	Y	NA	Y	Y	N	UC	Y	Y	UC	Y	Y
Ristolainen et al. (Ristolainen et al., 2014)	Y	NA	N	Y	Y	UC	Y	N	N	N	Y
Krüger et al. (Krüger et al., 2012)	Y	NA	N	N	N	UC	N	N	N	N	Y
Cross-Sectional	Were the criteria for inclusion in the sample clearly defined?	Were the study subjects and the setting described in detail?	Was the exposure measured in a valid and reliable way?	Were objective, standard criteria used for measurement of the condition?	Were confounding factors identified?	Were strategies to deal with confounding factors stated?	Were the outcomes measured in a valid and reliable way?	Was appropriate statistical analysis used?			
Martins et al. (Martins et al., 2018)	N	Y	Y	Y	N	N	N	Y			
de Almeida et al. (de Almeida et al., 2015)	Y	Y	N	N	N	N	N	Y			
Harrington et al. (Harrington et al., 2014)	Y	Y	N	Y	N	N	Y	Y			
Tate et al. (Tate et al., 2012)	N	Y	N	Y	N	N	Y	Y			
Tessaro et al. (Tessaro et al., 2017)	Y	Y	Y	Y	Y	Y	Y	Y			
Hidalgo-Lozano et al. (Hidalgo-Lozano et al., 2012)	Y	Y	N	Y	Y	Y	Y	N			
Hidalgo-Lozano et al. (Hidalgo-	Y	Y	N	Y	Y	Y	Y	Y			

Lozano et al., 2013)								
Cejudo et al. (Cejudo et al., 2019)	Y	Y	N	Y	Y	Y	N	Y
Capaci et al. (Capaci et al., 2002)	N	Y	N	Y	N	N	N	Y
Su et al. (Su et al., 2004)	Y	Y	UC	Y	Y	Y	Y	N

to develop shoulder pain. The remaining ten studies that reported on the relationship between training load and pain showed no significant difference or association.

Two studies investigated the relationship between training load and injury (Ristolainen et al., 2014; Tomar & Allen, 2019). Ristolainen et al. (Ristolainen et al., 2014) found a positive relationship and reported that the mean number of kilometres swam per year was significantly higher in injured swimmers when compared to non-injured swimmers (1612 km/year vs. 1380 km/year, $p = 0.04$). The second study reported no significant relationship between training load (r = −0.35), training monotony (r = 0.62), training strain (r = −0.12) or Acute/Chronic Workload Ratio (ACWR) (r = 0.08) and the incidence of injury (Tomar & Allen, 2019).

The risk of illness (i.e. Upper Respiratory Tract and Pulmonary Infections (URTPI)) was significantly higher ($p = 0.02$) during high load training periods, while the odds of having a URTPI was 70% and 50% higher during intensive training periods than both taper and competition periods, respectively (Hellard et al., 2015). High load workouts at maximal speed (blood lactate $\geq$ 10 mmo L^{-1}) contributed considerably to the increased risk (not specified) of URTPI. While the authors highlighted that the risks of URTPI were higher for swimmers during the winter months, they also specified that national swimmers were generally more at risk than international level swimmers despite similarities in age and training prescription. This may be explained by a superior genetic resistance response to infection or improved athletic lifestyle management by international swimmers, or a lower training load threshold by national level swimmers (Hellard et al., 2015).

4. Discussion

The aim of this systematic review was to investigate the relationship between training load and pain, injury and illness in competitive swimmers. A clear lack of consistency within the findings was evident, with conflicting results being presented and many methodological limitations preventing accurate comparison of results. This lack of consistent reporting prevented a meta-analysis of the results been conducted. There is no clear evidence of a relationship between training load and pain, with the majority of studies reporting no statistical difference or association between those with pain and their exposure to external training loads. This link would require further investigation using prospective study designs and coupling of both internal and external training load to get a more accurate representation. There is limited evidence to suggest a relationship between training load and injury with one study finding swimming more distance (km) in the past year increased the risk of injury (Ristolainen et al., 2014). This relationship would need to be investigated further with both internal and external training loads being used to accurately measure training load. There is also limited evidence for the relationship between training load and illness based on the work of Hellard et al. (Hellard et al., 2015); however, this needs further rigorous investigation in multiple swimming populations.

4.1. Participant demographics

The variability in findings is in keeping with the premise that pain, injury and illness are complex and multifactorial (Schwellnus et al., 2016; Wanivenhaus, Fox, Chaudhury, & Rodeo, 2012), with no single variable predicting maladaptation (Soligard et al., 2016). It is well documented that factors including chronological age, training age, injury history and physical capacity can impact an athlete's training response (Gabbett, 2016). Chronological age and training experience were two factors which varied greatly within this review. Two studies found significant, but contrasting findings between training load and pain in this review (Capaci et al., 2002; Krüger et al., 2012). Capaci et al. (Capaci et al., 2002) focused on male competitive swimmers with a young mean age (14.44 ± 2.4 years) and found swimming more hours per week influenced the presence of pain. This is in contrast to Krüger et al. (Krüger et al., 2012), who solely focused on masters level swimmers (mean age 49.6 ± 12.29 years) and found swimming lower volumes per week to be a risk factor for shoulder pain. This may be explained by the considerable changes experienced with ageing, i.e. loss of muscle mass, strength and function, alterations called sarcopenia (Volpi, Nazemi, & Fujita, 2004). This age-related decline also extends to a loss of tendon stiffness, resulting in decreased force transfer capabilities (Reeves, Narici, & Maganaris, 2006). The rotator cuff is among the most common clinical tendon problems for the ageing population (McCarthy & Hannafin, 2014), with the risk of having a full-thickness tear being 2.69 times greater in older adults than adults 10 years their junior (Fehringer, Sun, VanOeveren, Keller, & Matsen, 2008). Older athletes face an accumulation of residual injuries which may limit their training volume and intensity, thus causing a reduction in training adaptations (Foster, Wright, Battista, & Porcari, 2007). This can result in a cyclical pattern of reduced ability to train, causing a decreased training load and an increased susceptibility to musculoskeletal injuries. This is supported by Tate et al. (Tate et al., 2012) where the masters population swam less time per week than any other group within the study. The presence of pain at lower volumes may be a by-product of the '*injury prevention paradox*', where higher loads are thought to have a protective effect against injury (Gabbett, 2016). Masters athletes, swimming at lower loads, may be more susceptible to injury as they never reach the desired threshold of training to provide a protective effect. The reported modifications in training volume with age are thought to be as a result of changes in stroke biomechanics. It has been reported that older swimmers have altered stroke biomechanics when compared with elite swimmers. This is understood to be driven by lower values of stroke length which may be explained by lower mechanical power and muscle strength (Ferreira, Barbosa, Costa, Neiva, & Marinho, 2016). The masters population, in an effort to reduce the effects of ageing and to break the cyclical pattern of load-related injuries should focus on appropriate recovery strategies between sessions, increased resistance training and complementary cross-training sessions (Foster et al., 2007).

The level of a swimmer is also deemed to be a contributing factor to their risk of injury. Tate et al. (Tate et al., 2012) explored the presence of shoulder pain across the lifespan of a swimmer. They found that as the competitive level increased, so did the training exposure in hours per week, up until 15–19 years old, after which it dropped off when entering masters level swimming. This study found that high school swimmers were most symptomatic and those swimmers with shoulder pain had significantly more swimming exposure than those without shoulder pain (1.5 ± 1.14 years, $p = 0.01$). However, this finding was not replicated in acute swimming load (hours/week). Unfortunately, this study did not include a collegiate swimming group within the study design, leaving a gap between those in high-school and masters level. Typically, it is thought that the collegiate swimming population are at increased risk of injury in the first twelve months of joining a varsity swim team (Wolf, Ebinger, Lawler, & Britton, 2009). This was a key finding by Wolf et al. (Wolf et al., 2009) who reported the highest number of injuries during the first year of eligibility, followed by a substantial drop off in the subsequent years. In this study, male and female swimmers had a mean number of injuries of 1.21 and 1.19 in their freshman year compared to 0.71 and 0.46 in their senior year (Wolf et al., 2009). This is likely due to the transition from high-school or club swimming coupled with a sudden increase in training demands, followed by acclimatisation in those that do not drop out of the sport. Of the two collegiate swimming populations included in this review, one was not a true representation of a high-level varsity programme due to the low loads presented (Tomar & Allen, 2019), while the second was a National Collegiate Athletic Association (NCAA) Division I population, swimming 18.8 h/week (Harrington et al., 2014). Neither study found a statistically significant relationship between training load and pain or injury; however, the stage of collegiate swimming was not investigated in either study. This could mean that the population investigated had become acclimatised to such a training demand or those who experience pain or injury during the transition from high-school to college do not continue to compete at that level (Harrington et al., 2014; Wolf et al., 2009).

In an elite population, Hellard et al. (Hellard et al., 2015) found a higher risk of pathology in national level swimmers compared to international level swimmers. Coaches should consider the level of individual swimmers, understanding that swimmers of lower ability may be more susceptible than their counterparts. National level swimmers may be of a lower training age or capacity causing a decreased resistance to illness in comparison to their international level counterparts (Hellard et al., 2015). More mature international level athletes may also manage the training lifestyle demands better than their national level peers. Coaches should ensure that the swimmers' level is considered and modified for when planning training loads and session intensity.

4.2. Operational outcome definition

It has been clearly reported that inconsistencies in the methodological approach and definitions can create significant variations in findings (Fuller, 2006). While a number of consensus statements have provided clarity in the use of standard terminology over recent years, disparities in definitions stem from the specific sporting context for which the statements are developed (Bahr et al., 2020). A total of four (Cejudo et al., 2019; Martins et al., 2018; Tessaro et al., 2017; Tomar & Allen, 2019) of the included studies were published after the release of the 2016 FINA consensus statement with none of them making reference to the guidelines and recommendations. A host of outcome definitions were used amongst the 15 studies included in this systematic review, showing large inconsistencies that may be a factor in the conflicting nature of the findings. Many of the definitions reported an element of TL from the sport, a restriction in training or the need to have sought MA. While the use of this terminology is appropriate and commonplace in many sports, they have limitations when applied to sports such as swimming, where few traditional TL injuries occur (Bahr, 2009). As many swimmers tend to train in the presence of pain (Hibberd & Myers, 2013), using a traditional TL injury definition may mask and under-report the true impact of such pain/injuries (Bahr, 2009). Successful injury and illness prevention protocols rely on the correct categorisation of surveillance data (Palmer-Green et al., 2013). The consensus statement from FINA on injury and illness reporting was published in 2016 and provides a clear framework to be implemented in such cases (Mountjoy et al., 2016). Though this consensus statement provides clarity of the use of set definitions for injury, illness, TL and MA classifications, it also highlighted the need to prospectively monitor symptoms and complaints through the use of The Oslo Sports Trauma Research Centre (OSTRC) questionnaire. The OSTRC questionnaire has been validated in swimming and can be implemented longitudinally to record medical conditions that include complaints not leading to absence from the sport (Mountjoy et al., 2016).

While the development of a sport-specific consensus statement is a positive step towards consistency in reporting, the optimisation of the dissemination procedure and uptake of the key principles is a crucial aspect of the process. Even though researchers working within a specific related field may be aware of such consensus statements, those working at a practical level may have limited knowledge. The utilisation of consensus statements can be determined by the perception of relevance within a set period of time as developments of these concepts are rapidly evolving. As consensus statements can take 12–18 months to develop, the time elapsed between evidence discussion and collation, and recommendations published is crucial (Kwong, Chen, & Sun, 2016). Developing and disseminating consensus statements in a timely manner is essential to their effectiveness and relevance (Kwong et al., 2016). Consensus statements might benefit from undergoing a “knowledge management” process. Knowledge management is the process of simplifying and improving the creation, sharing and distribution of knowledge within a system (Gasik, 2011). A link between those that develop the consensus statement and the relevant National Governing Body (NGB) should be formed as part of the dissemination process. Providing clear educational strategies to the NGB should be a cornerstone of the dissemination process, allowing the key information to be communicated and understood at the practitioner level.

4.3. Relationship between training load and pain

The relationship between training load and pain was evaluated in twelve of the fifteen studies included in this review. A total of two studies found statistically significant differences or associations between a measure of training load and pain (Capaci et al., 2002; Krüger et al., 2012). A large percentage (60.5%) of competitive male swimmers reported musculoskeletal pain through the use of a questionnaire (Capaci et al., 2002). Those who experienced pain spent more time training (training history (years) or training hours per week) than those without pain. This suggests that those with a longer training history, and who swim more hours per week, have an increased chance of experiencing musculoskeletal pain. This finding challenges the traditional high-volume approach which spurs the quantity versus quality debate. Nugent et al. (Nugent, Comyns, & Warrington, 2017) discussed this concept with expert swimming coaches. Coaches tended to defend the high-volume swimming approach, particularly in youth swimming, as it promotes a large aerobic base and aids in technical development. However, they clarified that this should transition to a quality or more intensity-based training system as the swimmer improves (Nugent et al., 2017). This finding is also in contradiction with the theory that training load can have a protective effect (Gabbett, 2016); however, the age of those with pain was relatively young (14.78 ± 1.56 years). A swimmer’s ability to acclimatise and develop robustness to higher training thresholds may be impacted by maturation (Difiori, 2002), and therefore training hours should be gradually increased and adjusted for the pubertal development of the athlete (Corso, 2018).

While maturation was not investigated in the current review and research on the impact of maturation on injury is unclear (Bowerman, Whatman, Harris, Bradshaw, & Karin, 2014), coaches should be cognisant of the effects of an adolescent growth spurt on their training ability (Corso, 2018). A similar youth age category was investigated in four studies (Cejudo et al., 2019; Tate et al., 2012; Tessaro et al., 2017; Walker et al., 2012). All four studies found no statistically significant relationship between pain and training load when hours per week, kilometres per week or frequency of sessions per week were examined. Su et al. (Su et al., 2004) reported no difference in healthy swimmers compared with swimmers with shoulder pain (7.6 ± 5.3 vs. 8.1 ± 5.1 h/week, $p = 0.80$) and (3.3 ± 1.1 vs. 3.0 ± 0.9 km/session, $p = 0.33$) respectively (Su et al., 2004). Swim training distance was not a significant predictor of SIP or significant shoulder injury (SSI) (SIP: OR 1.0, 95% CI 1.0–1.0; $p = 0.07$/SSI: OR 1.0, 95% CI 1.0–1.0; $p = 0.11$) (Walker et al., 2012). A similar finding reported no statistically significant difference between pain and weekly volume ($p = 0.31$) (Tessaro et al., 2017). Training hours/week showed no difference in those with and without pain across a number of age groups (8–11 years, $p = 0.18$; 12–14 years, $p = 0.56$; 15–19 years, $p = 0.71$; masters, $p = 0.06$).Where hours per week were monitored, 12-19 year-old swimmers were training approximately 9–16 h per week (Tate et al., 2012). In youth swimming, training capacity needs to be carefully developed as their technical stroke mechanics improve. Technical aspects such as changing from unilateral to bilateral breathing may be improving, potentially resulting in a period of disruption and an increased risk of shoulder pain as they develop (Tate et al., 2012). In populations ranging in age from 18 to 30 years old, the training demand typically increased, with five studies reporting average training load ranges of 18.8–26.8 ($\pm$4.8) hours per week, or 45 ($\pm$20) - 57.1 ($\pm$29.9) km/week. No difference was found in any of the studies for those with and without pain. These increased training loads suggest that the external training load prescribed increases with age, which is in agreement with Feijen et al. (Feijen et al., 2020). However, the subsequent lack of increased pain suggests that as the athlete ages, their ability to tolerate increased external training loads is improved. Another reason may be those athletes that do not experience pain are more likely to remain in the sport for longer periods. By tracking external training load (km/session or hr/week) alone, these studies may have been unable to quantify the individual response to external training load, and thus a major risk factor for musculoskeletal pain may not have been detected.

Krüger et al. (Krüger et al., 2012) was the only study to find a negative association between training load and musculoskeletal pain. While the reported incidence of pain (62.4%) was similar to that of Capaci et al. (Capaci et al., 2002), the population and training load measure were different. It was found that the volume of training in meters/week was negatively associated with shoulder pain, meaning those that swam a lower volume (0–4,999 m/week) were 2.8 times more likely to develop shoulder pain than those that swam a higher volume ($\geq$12,000 m/week). These findings contrasted with the popular opinion that a swimmers pain is directly proportional to training volume (Contreras Fernandez, Liendo, Osorio, & Soza, 2012). While the age of this population could be a significant factor in this finding as discussed in section 4.1, there is another possible explanation. This finding could also be explained by the injury prevention paradox which highlights that low load can render an athlete less prepared and more susceptible to injury (Gabbett, 2016). The concept stipulates that excessively high loads may be inappropriate for individual athletes and can increase the risk of injury or illness. However, loads that are not high enough can also create an element of fragility within the athletes’ ability to tolerate load and have the same outcome. This concept reinforces the idea that training loads are not high or low but are appropriate or inappropriate for a specific individual. Coaches need to consider all the individual elements when planning appropriate loads to ensure a reduced risk of pain, injury or illness (Halson, 2014).

4.4. Relationship between training load and injury

The relationship between training load and injury was assessed in two of the included studies. The studies reported contrasting findings with one (Ristolainen et al., 2014) presenting the finding that injured swimmers had swum significantly more than non-injured swimmers in the past 12 months ($p = 0.04$). The second study (Tomar & Allen, 2019) stated that no association between measures of total training load (sRPE), training monotony, strain or

ACWR and incidence of injury was present. The populations and methods studied in both papers varied greatly. While Tomar and Allen (Tomar & Allen, 2019) used a common method of monitoring training load (sRPE) (Williams et al., 2017a), their population was not exposed to a rigorous training regime over a duration that is reflective of competitive swimming environments. Conversely, the population in Ristolainen et al. (Ristolainen et al., 2014) was an elite group of swimmers. However, the retrospective study design, coupled with a twelve-month recall period, the measurement of external training load and no quantification of internal training load means less confidence may be placed on the results.

4.5. Relationship between training load and illness

The relationship between training load and illness was investigated in one study meeting the required inclusion and exclusion criteria. The study utilised a prospective cohort design where training loads and illness was logged over a four-year period (Hellard et al., 2015). The population observed were elite-level swimmers, with both internal and external training loads being monitored. Training load was quantified in meters per week at each intensity determined by a blood lactate step test detailed by Mujika et al. (Mujika et al., 1996). Findings showed a positive relationship between training loads and illness with periods of high training loads (OR 1.10, 95% CI 1.01–1.19; $p = 0.02$) increasing the odds of illness by 50–70%. While this single study presents limited evidence, it does concur with the review of Drew and Finch (Drew & Finch, 2016) who summated that the relationship between training load and illness was found to be moderate. The review found a positive relationship in sports such as speed skating, Australian football, soccer and rugby league, with no relationship in an elite running population (Drew & Finch, 2016).

4.6. Monitoring training load

The studies included in this systematic review relied heavily on the use of self-reported data collected retrospectively through the use of questionnaires. This data is dependent on the athlete's ability to recall and report their individual training data accurately (Black, Gabbett, Cole, & Naughton, 2016). Previous research has shown that quantifying exercise dosage from data collected by questionnaire may be considered as inadequate (Borresen & Lambert, 2006), particularly with retrospective questionnaires, as the longer the recall period the less accurate the reported estimates (Kjellsson, Clarke, & Gerdtham, 2014). The majority of the retrospective studies used a twelve-month recall period (Ristolainen et al., 2014; Tessaro et al., 2017; Walker et al., 2012), with one spanning a three-year period (Krüger et al., 2012). Previous research has shown a twelve-month recall to be a sufficient method of collecting data (Mukherjee, 2015). However, in a study comparing retrospective and prospective injury surveillance data, a perfect agreement between the two methods was found when a simple yes or no answer was required. However, the accuracy of recall was severely diminished (approx. 40%) when specific details were required (Gabbe, 2003). This shows that the use of self-reported retrospective data for establishing patterns in sport should be avoided when detailed information is needed.

The relationship between training load and pain was evaluated using external training load in all twelve relevant studies. Of the two studies examining the relationship between training load and injury, one utilised a measure of external training load, with the second study reporting both internal and external training load. Finally, the relationship between training load and illness was assessed using both internal and external training load. The results showed that session duration (hours/week) was the most widely used external training load measure with swimming durations of 4.0 (±1.7)- 24 h/week, and was closely followed by distance per session (km). An external training load such as hours/week should be carefully implemented particularly in an advanced training environment. Beginner and intermediate athletes can focus on increases in training time to good effect; however, once a training programme has plateaued, any further increase in training hours can become unproductive resulting in session intensity being manipulated in order to achieve a training effect (Friel, 2018). Monitoring training distance (km/week) can also cause issues as the swim load measure cannot be extrapolated to other cross-training modalities such as resistance training. This leads to multiple measures of load being collected but unable to be combined or aspects of the training programme not being monitored at all. Another limitation of the exclusive use of external training load methods is that it does not accurately capture the athletes' individual response to the training dose and therefore internal training load needs to be combined with external load to provide greater insight to training stress (Bourdon et al., 2017). The use of sRPE has become one of the most commonly used measures of intensity in team sports. Session RPE, combined with session duration can provide an integrated training load measure capturing an athlete's external load and their individual response to it. An additional benefit of this approach is the ability to monitor sRPE globally across a training programme such as resistance training and cross-training, allowing for a holistic monitoring approach to all aspects of the programme (Williams et al., 2017a).

All but two (Hellard et al., 2015; Tomar & Allen, 2019) of the included studies used external training load exclusively as a means of quantifying training load. Bourdon et al. (Bourdon et al., 2017) summated that an integrated approach to training load monitoring is important as no single marker of an athletes response to load can consistently predict maladaptation (Soligard et al., 2016). Therefore internal and external load should be monitored in combination to provide greater insight (Bourdon et al., 2017). Tomar and Allen (Tomar & Allen, 2019) and Hellard et al. (Hellard et al., 2015) both used a combination of internal and external training load in line with current recommendations. Rating of Perceived Exertion was collected as a measure of internal training load and was monitored in conjunction with session duration by Tomar and Allen (Tomar & Allen, 2019). The data was analysed to provide measures of training load, monotony and strain (Foster, 1998; Foster et al., 2001) as well as ACWR, as outlined by Gabbett et al. (Gabbett, 2016). These training parameters were employed to find the relationship with the incidence of injury in a university swimming population over a seven-week period. No significant relationship was found between training load, strain and monotony or ACWR and the incidence of injury in this population, which contradicts earlier studies in a variety of sports (Anderson, Triplett-Mcbride, Foster, Doberstein, & Brice, 2003; Gabbett & Jenkins, 2011; Hulin et al., 2014). The lack of significant association could be due to the observational period being relatively short (seven weeks) or the low training load experienced by the group. A weekly mean training load of 260 ± 56.33 Arbitrary Units (AU) appears to be relatively low, compared to other competitive sporting populations. The mean weekly ACWR was 0.94 ±0 .53 with a peak of 1.03. These ACWR are within acceptable risk ranges according to Gabbett et al. (Gabbett, 2016) and combined with the low training load are unlikely to stress the athletes beyond their capacity (Gabbett, 2016).

Tomar and Allen (Tomar & Allen, 2019) was the only study in the review to use the Foster et al. (Foster, 1998; Foster et al., 2001) method of monitoring training load. This is in contrast to Eckard et al. (Eckard et al., 2018) whose multisport review of fifty-seven studies found twenty-two (39%) of those studies measured internal training load using the sRPE method. A similar multisport review conducted by Drew and Finch (Drew & Finch, 2016) found that twenty-five out of a total of thirty-five (71%) studies utilised sRPE. The significant difference between the frequency of sRPE use in swim specific research and multisport research highlights how underutilised this method of monitoring training load is in competitive swimming research.

Research surrounding training load has evolved to understand that neither high nor low training load can be considered solely at fault for pain, injury or illness (Gabbett, 2016). It is more central to consider the appropriate amount of training load or rate of load application for that individual athlete in order to maximise performance while simultaneously limiting maladaptation (Gabbett, 2019; Griffin, Kenny, Comyns, & Lyons, 2020). Research into monitoring changes in training load originated with Banisters "Training Stress Balance" method and developed into the ACWR in recent years (Griffin et al., 2020). The ACWR is designed to balance the most recent training loads (acute) with the athletes' recent history of training load (chronic) in an effort to predict how fit or fatigued they are (Hulin et al., 2014). The ACWR has been shown to quantify changes in training load by presenting a numerical range where training load is said to be at the "sweet spot" and injury risk is reduced (0.8–1.3) (Gabbett, 2016). It is important to note that this sweet spot numerical range can vary per population and individual physical capacities with team sports citing a ACWR sweet spot of 1.00–1.25 (Malone et al., 2017) and 0.85–1.35 (Hulin et al., 2014). This is crucial to an individual athlete sport like swimming where a squad "sweet spot" range cannot be relied upon and each individual's ACWR needs to be quantified. While a number of studies have used this method to good effect in a variety of sports (Bowen, Gross, Gimpel, Bruce-Low, & Li, 2020; Carey et al., 2017; Delecroix, McCall, Dawson, Berthoin, & Dupont, 2018; Hulin et al., 2014), the most accurate method of calculating the ACWR is contentious (Menaspà, 2017; Williams et al., 2017b). A recent review by Griffin et al. (Griffin et al., 2020) investigated the association between ACWR and injury in team sports. The review concluded that ACWR is associated with non-contact injuries which is a key finding for sports like swimming. The review also highlighted the key differences between the calculation of ACWR using the rolling average model and the exponentially weighted moving average (EWMA) model. The rolling average model divides the acute workload by the chronic workload whereas the EWMA model accounts for the decaying nature of fitness and fatigue by applying a greater weight to the most recent loads (Griffin et al., 2020). While the rolling average model has received more substantial attention in team sport research, the review states that EWMA may be a more sensitive measure (Griffin et al., 2020). The applicability of these models warrants further investigation, particularly in an elite swimming population where current research is severely limited.

Hellard et al. (Hellard et al., 2015) quantified intensity levels based on the work of Mujika et al. (Mujika et al., 1996) where blood lactate concentration was mapped throughout a swim specific step test (Mujika et al., 1996). Session intensities were planned accordingly and in conjunction with meters per week. Low-intensity training load was categorised as the mean percentage volume at intensity levels 1–3, while high-intensity training was categorised at intensity levels 4 and 5. Results of the study showed the odds of illness were 50%–70% higher during intensive training periods. The risk of illness was also increased during winter months, and in national level swimmers over international level swimmers. Coaches should be aware of the increased risks of URTPI during intensive training periods and should accurately measure and programme the intensity and overall load of the sessions accordingly. The scheduling of intensive training periods should be strategic, keeping non-sport stress in mind and avoiding periods of high academic or professional responsibilities, or demanding competition calendars. This is particularly important during the winter months where the population risk of URTPI is already considerably high (Hellard et al., 2015). The findings also showed that for every 10% increase in training load, a corresponding 10% increase in the risk of illness was likely, which is in agreement with current evidence that has shown very high training loads, very low loads and rapid changes in load can also contribute to illness (Schwellnus et al., 2016). The findings indicate that recovery strategies during intensive training blocks should be given higher consideration than normal. This is particularly important directly after acute maximal speed sessions (blood lactate $\geq$10 mmo L^{-1}) as these sessions contributed most to increasing risk of illness. This finding is in line with general consensus that immune disturbances are associated with acute session intensity (Walsh et al., 2011). A consensus statement by Walsh et al. (Walsh et al., 2011) highlighted that, in order to maintain immune health, training programmes should involve gradual increases in volume and intensity, avoiding sudden increases, adding variety of stimuli including cross-training methods and paying particular attention to recovery and nutritional strategies (Walsh et al., 2011).

5. Future considerations

The ability to synthesise the data and summarise the findings is significantly restricted by study design, a variety of training load methods, large variations in population and operating definitions of pain, injury, and illness. The guidance of a consensus statement may have aided authors in collecting both internal and external training load, which in turn would have improved the strength of the results. However, as only four (Capaci et al., 2002; Krüger et al., 2012; Nour et al., 2018; Su et al., 2004) of the studies included in this systematic review were published after the introduction of the most recent FINA (Mountjoy et al., 2016) and IOC (Schwellnus et al., 2016; Soligard et al., 2016) Consensus Guidelines covering load and the risk of injury and illness, their overall influence was diminished. Publication prior to 2016 reduced the likelihood of authors maintaining a high level of consensus in the operational definitions used for pain, injury and illness, as well as the protocols used to collect that information. Nevertheless, only one (Tomar and Allen, 2019) of the four studies highlighted made reference to the IOC consensus statement, with none referencing the FINA consensus statement. This systematic review highlights the need to refer to these guidelines prior to publishing research of this nature, ideally improving the study design and consistency across training load and injury/illness surveillance methods.

Conducting a meta-analysis was not possible within this review due to the large discrepancies between the studies' definitions, analyses, data collection methods and load measures. Future research should strive to rectify the limitations presented by this review by conforming to published consensus statements. If adherence to these guidelines was to increase going forward, the publication of a meta-analysis would be of significant benefit to researchers and practitioners alike.

The FINA guidelines also recommend in and out-of-competition monitoring of athletes using a sport-specific tool such as OSTRC (Mountjoy et al., 2016). This validated questionnaire has played an increasing role in sports injury and illness surveillance as it is purposefully designed for the collection of conditions that are below the time-loss threshold (Bahr et al., 2020).

Load monitoring is largely a subjective practice and thus is reliant on an athlete's recall of the key variables. While subjective measures have been shown to be more sensitive and consistent than objective measures in determining homeostatic changes to load (Schwellnus et al., 2016), their use in retrospective studies can lead to inaccuracies in data collection. Future research should focus on prospective cohort study designs as they are considered to be more reliable and generate real-time knowledge and allow for a more accurate estimation of the risk and incidence of injury and illness (Mukherjee, 2015).

While a variety of training load measures can be used in the monitoring of athletes, it is clear that no one measure will provide a clear picture when used in isolation. The reliance upon training volume as an external training load measure in a variety of forms was unable to determine a standardised variable suitable for a swimming population. To that end, in line with recent consensus statements, a combination of internal and external training load should be used in an integrated approach (Bourdon et al., 2017).

Future research also needs to explore the applicability of the sRPE method of monitoring internal training load within competitive swimming. A recent review by Eckard et al. (Eckard et al., 2018) found that 22/57 articles used the sRPE method to quantify session intensity. Statistically significant results were reported in 21 studies, with one study reporting all null findings (Eckard et al., 2018). The collection of sRPE in conjunction with additional external training load provides the opportunity to investigate the effect of not only increased loads but also changes in load. Unlike similar research in other sports, no study has investigated the links between training load and the incidence of pain, injury and illness in an elite swimming population using sRPE in a longitudinal prospective cohort study.

Finally, research into an elite competitive swimming populations is necessary to provide a clear picture of the associations between training load and pain, injury and illness for coaches and practitioners working at the highest echelons of the sport. Conducting research at an elite level is often difficult due to the limited access, numbers of athletes and the ability to implement good research processes in the practical training environments. However, there is greater control and resources available at that level, with less confounding factors affecting the results. A universal classification model as seen in Swann et al. (Swann, Moran, & Piggott, 2015) should be referred to when defining the athletes level of expertise, allowing for improved clarity and comparison of populations (Bahr et al., 2020).

6. Conclusions

This systematic review provides an appraisal of the literature examining the relationship between training load and pain, injury, and illness in competitive swimming. The findings highlight that the relationship between these variables is unclear owing to a host of methodological constraints associated with research in this field. While the relationship has yet to be established, the review highlights that youth, masters and competitive swimmers of a lower ability should receive particular attention. Planning of load within the seasonal calendar needs prudence, with winter months being a key period in the training cycle. Sessions of higher intensity and speed elements should be planned with caution. Monitoring and injury surveillance practices need to be developed in conjunction with consensus guidelines, ensuring load monitoring includes both internal and external training loads. The use of longitudinal load monitoring of elite populations, utilising sRPE and investigating the applicability of the ACWR and EWMA approaches should be a priority for researchers going forward. This will not only improve the quality of the research being conducted, it will also provide greater clarity on the relationship between training load and pain, injury, and illness.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Code availability

Not applicable.

Availability of data and material

Data and materials are available from the corresponding author, upon reasonable and appropriate request.

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Authors' contributions

All authors contributed to the review conception and design. Material preparation, data collection and analysis were performed by Lorna Barry, Tom Comyns, Mark Lyons, Karen McCreesh and Cormac Powell. The first draft of the manuscript was written by Lorna Barry and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Authors' information (optional)

Not applicable.

Declaration of competing interest

Lorna Barry, Tom Comyns, Karen McCreesh, Mark Lyons, Cormac Powell declare that they have no competing interests. Lorna Barry and Cormac Powell are employees of Swim Ireland, but this does not constitute a competing interest.

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List of abbreviations

NR	Not Reported
NPRS	Numerical Pain Rating Scale
DASH	Disability of the Arm, Shoulder and Hand Questionnaire
PSS	PENN Shoulder Score
SSQ	Shoulder Service Questionnaire
SIP	Significant interfering shoulder pain
SSI	Significant shoulder injury
MA	Medical Attention
NTL	Non- Time Loss
TL	Time loss
SR	Self-reported
Third-Party	Coach or Investigator reported information
CA	Clinical Assessment
RPE	Rate of Perceived Exertion
sRPE	Sessional Rate of Perceived Exertion
freq/wk	Frequency per week
hr/wk	Hours per week
Km/wk	Kilometres per week

m/wk	Meters per week
+ive	Positive
IOC	International Olympic Committee
FINA	Fédération Internationale de Natation
JBI	Joanna Briggs Institute
ACWR	Acute Chronic Workload Ratio
EWMA	Exponential Weighted Moving Average
NCAA	National Collegiate Athletic Association
URTPI	upper respiratory tract and pulmonary infections
OSTRC	Oslo Sports Trauma Research Centre
NGB	National Governing Body

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ptsp.2021.01.002.

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