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Highlighting gaps in the reporting of aerobic exercise interventions for mild traumatic brain injury: A systematic review using the TIDieR-Rehab checklist

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ABSTRACT

Objective: To assess intervention reporting quality in randomised controlled trials (RCTs) comparing aerobic exercise with control interventions following mild traumatic brain injury (mTBI).
Methods: Five databases were systematically searched for RCTs that compared the effect of aerobic exercise interventions with no intervention or another control, on symptom severity or recovery, in adolescents or adults with mTBI. Two reviewers independently screened articles, extracted data, and rated reporting quality using the TIDieR-Rehab checklist. Reporting completeness was quantified by intervention group and TIDieR-Rehab item. Authors were contacted to determine if reporting could be improved.
Results: Within 13 included studies, overall reporting was moderate (62 % of TIDieR-Rehab items complete). Dosage items 'Frequency' (85 %) and 'Intervention length' (96 %) were well reported, whereas 'Session duration', 'Essential elements amount', 'How challenging', and 'Regression/Progression' were moderately reported (54 %–65 % complete). Personalisation and protocol deviations were poorly reported (12 %–23 %). On average, authors supplied 71 % of missing intervention details on request.
Conclusions: The TIDieR-Rehab checklist revealed critical reporting gaps. Incomplete reporting of aerobic exercise parameters hinders clinical translation and limits investigation of optimal dosage parameters and underlying mechanisms. Poor reporting of personalisation and protocol deviations may mask necessary adaptations for individuals with mTBI. To improve reporting in this field, it is recommended that researchers utilise the TIDieR-Rehab checklist when planning and reporting their studies.

Key points

- Aerobic exercise interventions are not comprehensively described in mTBI RCTs
- Reporting of active time, challenge, and regression/progression, was often lacking
- Personalisation was poorly reported but may be essential to clinical translation
- Better reporting will enable researchers to deconstruct and optimise the essential elements of aerobic exercise, while also supporting effective replication in clinical practice
- The TIDieR-Rehab checklist can aid thorough intervention planning and reporting

1. Introduction

Traumatic brain injury occurs when brain tissues are stretched or compressed due to external mechanical forces [1]. The majority are classified as mild traumatic brain injuries (mTBIs) based on initial presentation (loss of consciousness <30 min, Glasgow Coma Scale ≥13, and post-traumatic amnesia <24 h), and in milder mTBI cases, where neuroimaging is normal or not indicated, the injury is commonly called concussion [1]. The estimated annual incidence of mTBI is between 12 and 57 million cases globally [2,3]. People with mTBI commonly experience symptoms such as headaches, dizziness, sensitivity to noise or light, and difficulty concentrating [4], resulting from complex pathophysiological processes involving changes in cerebral blood flow, cell osmolarity, and metabolism, and coinciding with vestibulo-ocular and cervicogenic dysfunction [4,5]. Recovery after mTBI varies, but approximately 50 % of people are still symptomatic 12 months post

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injury [6] and economic and social costs are still apparent four years after injury [7].

Exercise is now widely accepted as a key aspect of mTBI rehabilitation [8]. Systematic reviews demonstrate that early aerobic exercise can reduce recovery time and symptoms, compared with rest, stretching, or gradual resumption of activity [9,10]. Of the various aerobic exercise approaches, sub-symptom aerobic exercise is particularly promising [11]. Sub-symptom aerobic exercise uses a graded exercise test, such as the Buffalo Concussion Treadmill Test (BCTT), to determine the exertion level at which symptoms are exacerbated [5], and then exercise is prescribed below this threshold [5,12]. This approach has been shown to increase recovery rate and reduce the likelihood of persistent symptoms [13,14].

Intervention dosage parameters such as 'amount' and 'challenge' appear to influence the effectiveness of aerobic exercise following mTBI [15]. 'Amount' encompasses the volume of intervention, including the session duration, session frequency, and programme length [16], and observational evidence shows an association between higher volumes of aerobic exercise (>100 min a week) and reduced mTBI symptom severity [17]. However, broader rehabilitation literature suggests that the time spent engaged in the essential elements of the intervention which are thought to drive recovery may be more important than overall session duration, which often includes non-essential elements such as preparation, cooldown, or rest periods [18]. 'Challenge' or intensity of effort is a multifaceted rehabilitation parameter. In aerobic exercise, challenge can be set and monitored according to the exercise parameters (e.g., mode of exercise, speed, resistance), physiological intensity relative to the person's capacity (e.g., heart rate (HR) at symptom onset, age-predicted maximal HR), or subjective experience (e.g., rating of perceived effort) [12]. While research suggests challenge may be integral to driving outcomes [5,19,20], no studies have directly evaluated the effect of different challenge levels in aerobic exercise following mTBI, and the relationship between challenge and the mechanism of effect is not well understood [5,12]. Animal models of traumatic brain injury show that voluntary aerobic exercise promotes adaptive neuroplasticity and improves cognitive performance [21,22], and in humans, sub-symptom aerobic exercise has been linked with normalised cerebral blood flow and symptom improvement [23,24]. However, early initiation of high intensity exercise may impede recovery [25], suggesting that the timing of challenging exercise is also important. Thus, the literature suggests intervention parameters such as challenge, amount, and timing of aerobic exercise may drive mechanisms that facilitate or hinder mTBI recovery, however, there is little consensus about the optimal aerobic exercise parameters [12].

The development of knowledge about optimal aerobic exercise parameters following mTBI is hindered by poor reporting [15,26]. Without clear reporting, interventions cannot be accurately replicated, and the effects of specific intervention parameters cannot be explored through meta-analyses, limiting the identification of the essential elements which drive recovery [15,27,28]. The 12-item Template for Intervention Description and Replication (TIDieR) checklist was published in 2014 to promote complete intervention reporting [27]. However, reporting issues persist [29], particularly in the detailed breakdown of dosage parameters relevant to rehabilitation interventions [29,30]. In response, Signal et al. [31] developed the TIDieR-Rehab checklist, an extension to the original TIDieR checklist tailored specifically to rehabilitation interventions. This 22-item checklist provides a more comprehensive framework, breaking down dosage parameters, such as amount and challenge, and addressing critical aspects such as the intended patient population, intervention timing, personalisation, and safety [31].

Previous reviews of mTBI interventions have utilised tools such as the original TIDieR [27] or Consensus on Exercise Reporting Template (CERT) [32] but these reviews have encompassed a broad scope, examining all non-pharmacological interventions [33] or physical exercise interventions [34] for mTBI. While these reviews found excellent reporting completeness (90–95 %) for items aligned with dosage [33,34], the tools utilised lacked the specificity required to fully understand the intervention parameters. By contrast, the TIDieR-Rehab checklist enables a more detailed analysis of rehabilitation intervention reporting, offering the potential to identify previously unreported details that are critical to understanding which parameters of aerobic exercise may drive positive outcomes [31,33,34]. Therefore, this systematic review aimed to determine the intervention reporting quality within randomised control trials investigating aerobic exercise following mTBI using the TIDieR-Rehab checklist.

2. Methods

2.1. Study design

This systematic review was undertaken in accordance with the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines [35] and was prospectively registered (Prospero CRD42024496206).

2.2. Search strategy

A systematic search was carried out on 8th February, 2024 using the following databases: EBSCO (CINAHL, MEDLINE, SPORTDiscus), Scopus, AMED and Cochrane Central Register of Controlled Trials (CENTRAL). The databases were searched from inception and the search terms were synonyms of three key concepts: mTBI; aerobic exercise; and RCT (see Supplementary File A for search terms optimised for each database). Additional citations were sought by hand-searching relevant reference lists. After removal of duplicates, two independent researchers (IT, SO) utilised Rayyan online software [36] to screen citations by title and abstract, and full text where necessary, according to the eligibility criteria. Studies were included if they: i) studied adolescents over 10 years or adults with a diagnosis of mTBI or concussion, ii) investigated the effect of an aerobic exercise intervention, iii) made comparisons with either no intervention or another intervention, iv) measured pre- and post-intervention measures of symptom severity or time to recovery, v) were RCT or quasi-RCT design, and vi) were published in peer-reviewed journals in English with full-text available. Aerobic exercise was defined as repetitive, structured physical activity that requires the body's metabolic system to use oxygen to produce energy over a prolonged period [37] and needed to be initiated at or after mTBI/-concussion diagnosis, involve at least three exercise sessions (supervised or unsupervised), and if applied alongside other adjunct interventions (such as stretches, balance exercises, cervical mobilisations), the adjunct interventions were required to be attention- and dose-matched between groups. If aerobic exercise was included, but the primary focus of the intervention was balance, vestibular therapy, or strengthening, the article was excluded. Where trial protocols or registrations were identified, the registration number and principal investigator information were used to search for additional publications of results. Any disagreement after screening was resolved with discussion, or, if necessary, through consultation with a third researcher (EG).

2.3. Data extraction and assessment of quality of intervention reporting

Key study characteristics including study design, population (including time post-injury and sport participation), sample size, experimental intervention, and control intervention were extracted into a Microsoft Excel spreadsheet.

The quality of reporting for experimental and control interventions was assessed using the TIDieR-Rehab checklist (see Supplementary File B for item descriptors) [31]. To facilitate this process, two tools were developed: i) a Microsoft Excel spreadsheet for data extraction and

rating of the 22 TIDieR-Rehab items, and ii) a Table of Reference describing domain specific reporting criteria for each item informed by clinical experience with mTBI, examples from mTBI aerobic exercise studies, and the TIDieR-Rehab supplementary manual [31] (see Supplementary File C). Both tools were tested and refined using four articles that did not meet the review eligibility criteria. Data extraction and TIDieR-Rehab ratings were independently conducted by two researchers (IT, EG). Relevant information for each TIDieR-Rehab item was extracted from the main article, supplementary material, or any additional articles referenced in the study method, including pre-trial registrations. Each TIDieR-Rehab item was rated as 'complete' (sufficient detail for replication) [38], 'incomplete' (present but insufficient for replication), or 'absent' (no relevant information). Inter-rater agreement prior to consensus was assessed with the linear weighted Cohen's kappa [39]. The researchers met to reconcile disagreements in ratings after evaluating the first 30 % and the remaining 70 % of studies. Disagreements were resolved through discussion, with unresolved cases mediated by a third researcher (SO). Once agreement was reached, the Table of Reference was updated as needed to reflect consensus.

A summary of 'incomplete' and 'absent' items was subsequently emailed to study authors (corresponding author initially, then last or second author after two weeks), to determine if authors could provide missing information (see example in Supplementary File D). While these responses did not alter the main TIDieR-Rehab ratings they were evaluated against each item to calculate improvements post feedback.

2.4. Data analysis

Study characteristics and TIDieR-Rehab ratings were summarised descriptively and with figures using Microsoft Excel. TIDieR-Rehab ratings were presented and the percentage of 'complete' items per study and per TIDieR-Rehab item were calculated, for both experimental and control interventions, as was percentage of items converted from absent/incomplete to complete after author feedback. Reporting quality was categorised as good (>80 % items completely reported), moderate (50–79 % items completely reported) or poor (<50 % items completely reported) [33]. Dosage and personalisation elements for each study were presented in a summary table.

3. Results

3.1. Study selection

Following eligibility screening, 14 articles, comprising 13 studies, were included in the review (see PRISMA flowchart in Fig. 1). One study, reported in two articles [40,41], has been combined for the purposes of this review.

3.2. Study characteristics

All included studies were published from 2015. The study characteristics are summarised below, with further detail provided in Supplementary File E.

3.2.1. Participants

The study populations were adolescents (aged 10–19 years) in eight studies [13,14,40–46], a combination of adolescents and young adults (aged 13–25 years) in two studies [17,47], and adults in three studies [48–50]. The proportion of males and females was similar in 10 of the 13 studies, while two studies enrolled predominately males [14,43] and one study enrolled predominately females [50]. Sample sizes ranged from 15 to 456 participants (n = 1290 included in review). The populations were acute (within 2 weeks of injury) in nine studies and ranged from 2 weeks to 6 months post injury in the other four studies [40,41,45,46,49]. The cause of injury was sport-related in six studies [13,14,43,45,47,50] and a combination of sport and non-sport related in the other seven studies [17,40–42,44,46,48,49]. All studies were completed in North America.

3.2.2. Experimental aerobic exercise interventions

The experimental aerobic exercise intervention was sub-symptom aerobic exercise in seven studies [13,14,17,40,41,44–46]; six of these set challenge at 80–90 % of the HR threshold that exacerbated symptoms during baseline testing [13,14,17,44–46]. For the remaining studies, two investigated aerobic exercise based on subjective exertion levels (one used 0–6/10 Borg rating scale [50] and the other progressed physical activity using the PCERT scale [42]), three studies investigated

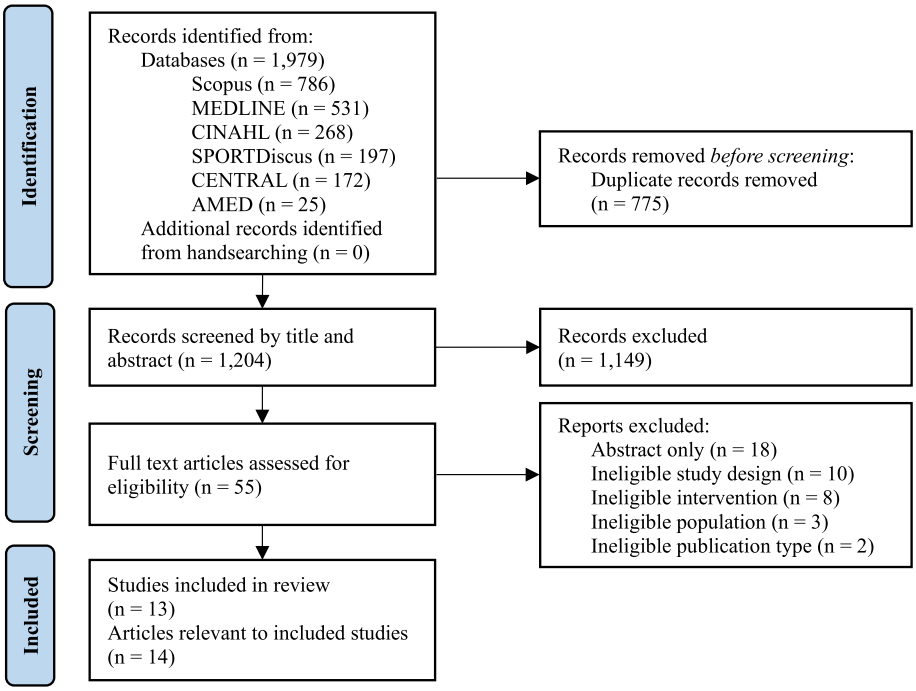

Fig. 1. PRISMA flowchart.

aerobic exercise based on absolute HR values, irrespective of symptoms [43,47,49], and a final study gave hospital discharge instructions for light aerobic exercise (e.g., walking) [48]. Other dosage and personalisation parameters of the experimental aerobic exercise interventions are described in Table 1. The reported session duration ranged from 20 to 60 min, frequency was 5–7 days per week, and programme length was 1–8 weeks. The intervention setting was unsupervised home or community-based exercise in eight studies [13,14,17,40–42,44,45,48], a combination of home-based and supervised sessions for two studies [46,47], while the exercise in three studies was entirely conducted under supervision within research centres [43,49,50].

3.2.3. Control interventions

The control intervention was stretching in five studies [13,14,40,41,45,49], while seven studies were 'usual care' consisting of physician advice without formal exercise prescription [17,43,44,47], return to activity after symptom resolution [42,48], or no active exertion [50], and one study used a stretching phase followed by a walking phase [46]. Control interventions were matched with their respective experimental interventions in terms of session duration, frequency, and program length in six studies [13,14,40,41,45,46,49], while five studies only matched program length [17,43,44,47,50]. Two studies [42,48] investigated very similar experimental and control interventions but delayed initiation of the control until participants were symptom free.

3.3. Quality of intervention reporting

3.3.1. Agreement on TIDieR-Rehab rating

Inter-rater agreement prior to consensus was 77 % (Cohen's kappa = 0.63) for the first 30 % of studies and 73 % (Cohen's kappa = 0.59) for the remaining 70 % of studies, indicating moderate to substantial agreement between the two researchers [51].

3.3.2. Intervention reporting quality for TIDieR-Rehab checklist items

Across both experimental and control interventions, there was moderate-quality reporting of TIDieR-Rehab items with 62 % of items rated 'complete', 21 % of items rated 'incomplete', and 17 % of items rated 'absent'. Figure 2 illustrates the rating of TIDieR-Rehab items for the experimental and control interventions across the 13 included studies.

Most studies (11/13) 'completely' reported at least 50 % of items, but none were rated 'complete' across all 22 items. The highest-rated study [14] had 'complete' reporting for 91 % of items for the experimental intervention and 81 % of items for the control. In contrast, the lowest-rated studies 'completely' reported 25 % of items [46] and 43 % of items [43] across experimental and control interventions. Experimental aerobic exercise interventions had a higher proportion of items rated 'complete' (65 %) compared with control interventions (59 %). Experimental interventions had some information (either 'complete' or 'incomplete') on 59 % of items, compared to 27 % for control interventions.

Reporting varied widely across individual TIDieR-Rehab items. Figure 3 shows the number of studies that 'completely' and 'incompletely' reported each TIDieR-Rehab item. The best reported items, 'Brief name' and 'Intervention length', were 'completely' reported for 100 % of experimental and 92 % of control interventions. Other items with good reporting (>80 % complete) were 'Who', 'When', 'Procedures', 'How', and 'Frequency'. The items with the least 'complete' reporting were 'Personalisation to Needs' (12 % complete), 'Personalisation to Preferences' (15 % complete), and 'Protocol deviations' (23 % complete). Additionally, 'Why' and 'Who provided' were poorly reported (<50 % complete).

3.3.3. Missing information obtained from authors

The authors of 12 of 13 studies (92 %) replied via email, and nine (69 %) supplied further information and/or study protocol documents related to the missing information. Reporting completeness improved to 78 % following feedback, with two studies having 100 % [13,14] and three studies having over 90 % [45,49,50] 'complete' reporting. Across the nine studies that provided additional information, on average, these studies improved the reporting to a 'complete' rating in 71 % of the items initially deemed 'absent' or 'incomplete'. Further detail on changes following author feedback can be seen in Supplementary File F.

4. Discussion

Accurate and comprehensive reporting of interventions is critical for advancing research and clinical practice. This systematic review, utilising the TIDieR-Rehab checklist, offers a detailed examination of the reporting quality of aerobic exercise interventions following mTBI. The findings highlight that while parameters like frequency and intervention length were well-documented, critical details such as session duration, challenge level, and regression/progression were often incomplete or absent. This review builds on prior reviews which used the original TIDieR checklist [33,34] by highlighting areas of rehabilitation reporting which were previously underexplored. These findings reinforce the urgent need for standardised reporting practices that enable researchers to deconstruct and optimise the essential elements of aerobic exercise for mTBI, while providing clinicians with evidence-based protocols which can be implemented in clinical practice.

The amount of aerobic exercise undertaken within an intervention programme depends on the programme length, session frequency, and session duration. While programme length and session frequency were generally well reported, critical details regarding 'Session duration' and the 'Essential elements amount' were poorly reported. Distinguishing between 'Session duration' and the 'Essential elements amount' is a critical yet often overlooked aspect of reporting in mTBI interventions [15]. In aerobic exercise, the essential elements refer to the time spent working at the prescribed challenge level, excluding non-therapeutic components such as warmups, cool downs, and breaks (see example in Table of Reference, Supplementary File C). Yet only 31 % of studies made this distinction in both the experimental and control interventions. This distinction is crucial, as overestimating or misrepresenting active exercise time can obscure the actual dose delivered, undermining the validity of meta-analyses and subgroup analyses investigating mechanisms of effect [15]. Furthermore, when implementing the intervention in clinical practice, this lack of clarity may result in either insufficient doses which fail to yield the desired outcome [12] or excessive exercise durations that may lead to fatigue, symptom exacerbation, or other adverse consequences that hinder recovery [19]. Without precise reporting of 'Session duration' and the 'Essential elements amount', interventions remain difficult to be reliably replicated nor can they effectively inform sub-group analyses in meta-analyses investigating mechanisms of effect [27,28].

Setting, monitoring, and regressing/progressing the intervention amount and challenge level is critical to the safety and efficacy of aerobic exercise interventions following mTBI [5,15]. 'How challenging' and 'Regression/Progression' were at least partially reported in 96 % and 100 % of studies, but only completely reported in 65 % and 54 % of studies respectively. This suggests that study authors recognise the importance of these parameters but often failed to provide the level of detail required to effectively replicate these aspects of the intervention. For example, the TIDieR-Rehab not only requires reporting of the target challenge level (e.g., HR threshold), but also the mode of exercise (e.g., treadmill) and the specific parameters manipulated to reach that challenge level (e.g., whether speed or incline was increased to reach challenge level). Such detail is necessary to fully understand the mechanism of effect, as illustrated by prior research in healthy populations which demonstrates that parameters such as cycling cadence affect brain derived neurotrophic factor release [52] and body positioning mediates changes in cerebral blood flow [53], both of which are thought to impact mTBI recovery [5]. Another inadequately reported area highlighted by

Table 1
Aerobic exercise intervention characteristics for TIDieR-Rehab items related to dosage and personalisation.

Author	Brief Name Item 1	Procedures Item 5b	Session Duration Item 9a	Essential Elements Amount Item 9b	Frequency Item 9c	Int Length Item 9d	How Challenging Item 10	Regression/ Progression Item 11	Personalisation to Needs Item 12a	Personalisation to Preferences Item 12b
Bailey et al. (2019) [46]	Subsymptom threshold exercise program	ETT: Balke treadmill test - 3.3 mph, 1m at 0 % incline, then ↑ to 2 % incline, then ↑ by 1 % incline/minute until ↑ symptoms. Ex prescription: Daily ex in clinic or home (home details NR)	NR	20m in clinic. Home ex NR	Daily (3x per w in clinic)	6w	Clinic: 80 % HR threshold where ETT stopped. Home: Challenge level NR. Mode/method to reach challenge level NR for clinic/home.	Progression: NR. Regression: NR	NR	NR
Chrisman et al. (2019) [45]	Sub-Threshold Exercise Program (STEP)	ETT: Modified BCTT - 3.3 mph, 1m at 0 % incline, then ↑ to 2 % incline, then ↑ by 1 % incline/minute until symptoms or 20m. Also measured baseline PA with actigraphy. Ex prescription: Daily home ex, self-selected mode. Self-monitored (wrist HR monitor).	5–10m more than baseline level of moderate-vigorous PA	NR	Daily	6w	80 % HR threshold where ETT stopped. Mode/method to reach challenge level self-selected	Progression: Duration ↑ 5–10m weekly aiming for goal of 60 m/day (specific decision rules NR). Regression: If symptoms ↑ during session, target HR ↓ 10 %	NR	Participant chose mode (most used ex bike, treadmill, fast walk on incline/ stairs, or calisthenics)
Howell et al. (2021) [17]	Individualized subsymptom threshold aerobic exercise prescription	ETT: Progressive cycle test - 3m at 50W (60-70RPM), 3m at 100W (70-80RPM), then resistance ↑ to 125–175W based on HR ↑ for 2m, then ↑ by 50 W/2m until 3-point symptom ↑ on VAS or 12m. Ex prescription: Individualised home ex instructions. Self-monitored (HR monitor)	NR	20m	5x per w	8w	80 % HR threshold where ETT stopped. Mode/method to reach challenge level self-selected	Progression: Target HR ↑ at 1 month with same ETT. Regression: NR	NR	Participant chose mode
Howell et al. (2022) [44]	Early aerobic exercise	ETT: Progressive cycle test - 3m at 50W (60-70RPM), 3m at 100W (70-80RPM), then resistance ↑ to 125–175W based on HR ↑ for 2m, then ↑ by 50 W/2m until 3-point symptom ↑ on VAS or 12m. Ex prescription: Individualised home ex instructions. Self-monitored	NR	20m	5x per w	4w	80 % HR threshold where ETT stopped. Mode/method to reach challenge level in home programme NR (i.e., ↑ resistance or RPM)	Progression: Not progressed. Regression: NR	NR	Implied that participant chose mode

(*continued on next page*)

Table 1 (*continued*)

Author	Brief Name Item 1	Procedures Item 5b	Session Duration Item 9a	Essential Elements Amount Item 9b	Frequency Item 9c	Int Length Item 9d	How Challenging Item 10	Regression/ Progression Item 11	Personalisation to Needs Item 12a	Personalisation to Preferences Item 12b
		(actigraphy device). Mode NR.								
Hutchinson et al. (2022) [47]	Structured aerobic exercise protocol (SAEP)	Ex prescription: 2 sessions in laboratory on stationary bike. Remaining sessions completed remotely via stationary bike, elliptical machine, treadmill, or outdoor jogging. Self-monitored HR (Fitbit device)	25m 1st session, 30m other sessions (incl 10m warmup, cool down)	15m, then ↑ to 20m	2d ex, 1d rest, repeated (total 8 sessions)	11d	60 % predicted HR max. Home: Mode/ method to reach challenge level varied. Clinic: cycling mode, method to reach challenge level NR (i.e., ↑ resistance or RPM).	Progression: 2nd session ↑ to 30m, from 3rd session HR ↑ 5 % HR max every 2 sessions. Method NR (i.e., ↑ resistance or RPM). Regression: Need for regression if symptoms ↑ noted, plan NR.	Advised to use stationary bike, but could use elliptical, treadmill or jog if no access to bike	NR
Kurowski et al. (2017) [40]; Gladstone et al. (2019) [41]	Subsymptom exacerbation aerobic training	ETT: Aerobic bike test - Borg RPE 11, resistance 2 for 5m, ↑ Borg by 1 point/5m until symptoms ↑ or to max 30m with max RPE 16. Ex prescription: Individualised home ex on stationary bike.	80 % duration of ETT	NR	5–6x per w	6-8w	80 % duration where ETT stopped, NR if Borg same as ETT or set. Cycling mode; method to reach challenge level NR (i.e., ↑ resistance or RPM)	Progression: Duration ↑ weekly with same ETT. Detail on method for ↑ challenge NR (i.e., ↑ resistance or RPM). Regression: NR	NR	NR
Leddy et al. (2019) [13]	Progressive subsymptom threshold aerobic exercise	ETT: Modified BCTT -3.6 mph, 2m at 0 % incline, then ↑ 1 % incline per minute until 3-point symptom ↑ on VAS or 20m. Ex prescription: Daily ex at home or supervised in gym using stationary bike or treadmill. Self-monitored (HR monitor)	NR	20m	Daily	30d	80 % HR threshold where ETT stopped. Mode was choice of stationary bike or treadmill, or walking/jogging if no equipment.	Progression: Target HR ↑ weekly with weekly ETT. Regression: Home sessions ceased if symptoms ↑ by 2 points on VAS.	Could walk or jog if no access to equipment	Mode and setting: bike or treadmill, home or gym. Who decided NR
Leddy et al. (2021) [14]	Individualised subsymptom threshold aerobic	ETT: BCTT - 3.2 mph (3.6 if $\geq 5'10''$), 2m at 0°, then ↑ by 1°/ minute to 15m, then ↑ speed by 0.4 mph/ minute until 3-point symptom ↑ on VAS or 20m. Ex prescription: Daily home ex (e.g., walking, jogging, stationary bike). Self-monitored (HR monitor)	20m (incl 10m warm up, cool down)	20m	Daily	4w	90 % HR threshold where ETT stopped. Mode/method to reach challenge level self-selected, examples were walking, jogging, stationary cycling	Progression: Target HR ↑ weekly with weekly ETT. Regression: Home sessions ceased if symptoms increased	NR	Participant chose mode
Ledoux et al. (2022) [42]	Stepwise return-to-PA protocol at	Ex prescription: Progressive return to PA, following 6-stage	NR	Stage 1 15m, other stages NR	Stage 1 + 2 daily, other stages NR	4w	Stage 1 was PCERT effort 3/10 Mode/method to	Progression: Required different PCERT levels during	NR	Sport-specific training included,

(*continued on next page*)

Table 1 (*continued*)

Author	Brief Name Item 1	Procedures Item 5b	Session Duration Item 9a	Essential Elements Amount Item 9b	Frequency Item 9c	Int Length Item 9d	How Challenging Item 10	Regression/ Progression Item 11	Personalisation to Needs Item 12a	Personalisation to Preferences Item 12b
	72h post concussion	protocol: 1) walking initiated 72h post injury, 2) light aerobic (e.g., jogging, swimming), 3) higher intensity sport-specific ex, 4) non-contact training, 5) full contact, and 6) and return to competition					reach challenge level was walking continuously	each stage to move to next stage. Each stage progressed in challenge level. Regression: If symptoms intolerable during or 30m after ex, regressed 1 stage for 1 day		but decisions rules unclear
Maerlender et al. (2015) [50]	Controlled, programmed daily physical exertion	Ex prescription: Daily ex on stationary bike in laboratory.	20m	20m	Daily	50d	0-6 on Borg 10-point RPE scale (low-moderate intensity). Cycling mode; method to reach challenge level NR (i.e., ↑ resistance or RPM)	Progression: Not progressed, but initial challenge level broad. Regression: Ceased session if uncomfortable.	NR	NR
Micay et al. (2018) [43]	Standardised aerobic exercise	Ex prescription: Supervised ex on stationary bike initiated 6 days post injury, with HR monitoring. Combined with 6-stage activity progression guided by sports physician.	20m 1st session, 30m other sessions (incl 10m warm up, cool down)	10m, progressed to 20m	2d ex, 1d rest, repeated	11d	50 % age predicted HR max. Cycling mode; method to reach challenge level NR (i.e., ↑ resistance or RPM)	Progression: 2nd session ↑ to 30m (20m at target HR), then HR ↑ by 5 % of age predicted HR max every 2nd session until 70 %. Detail on method for ↑ challenge NR (i.e., ↑ resistance or RPM). Regression: If symptoms ↑ by 3 on PCSS, session ceased, same session repeated next day	NR	NR
Snyder et al. (2021) [49]	Aerobic exercise	Ex prescription: Daily in-person ex on stationary bike. HR monitored with pulse oximeter.	55m (incl 5m warm up, 5m break, 5m cool down)	20m x 2	7 daily sessions, with 1 rest day in middle	8d	65–75 % of predicted HR max. Cycling mode; method to reach challenge level NR (i.e., ↑ resistance or RPM)	Progression: Not progressed. Regression: NR	NR	NR
Varner et al. (2021) [48]	Discharge instructions for 30m daily light exercise	Ex prescription: Advice and written instructions for daily light ex (e.g., walking, stationary cycling) initiated 48h post injury	30m	30m	5+ per w	30d	'Light activity that does not cause you to sweat or breathe harder'.Any mode, examples were walking or stationary cycling.	Progression: Not progressed. Regression: Advised to cease session if symptoms severe.	NR	Participant chose mode

Abbreviations: BCTT: Buffalo Concussion Treadmill Test; d: Days; ETT: Exercise tolerance test; Ex: Exercise; HR: Heart rate; HRmax: Heart rate maximum; h: hour; Incl: Including; Int: Intervention; m: Minutes; mph: Miles per hour; NR: Not reported; PA: Physical activity; PCERT: Pictorial Children's Effort Rating Table; PCSS: Post-Concussion Symptom Scale; RPE: Rate of perceived exertion; RPM: Revolutions per minute; W: Watts; w: week. Additional dosage parameters (unpublished) provided by authors are presented in Supplementary file F.

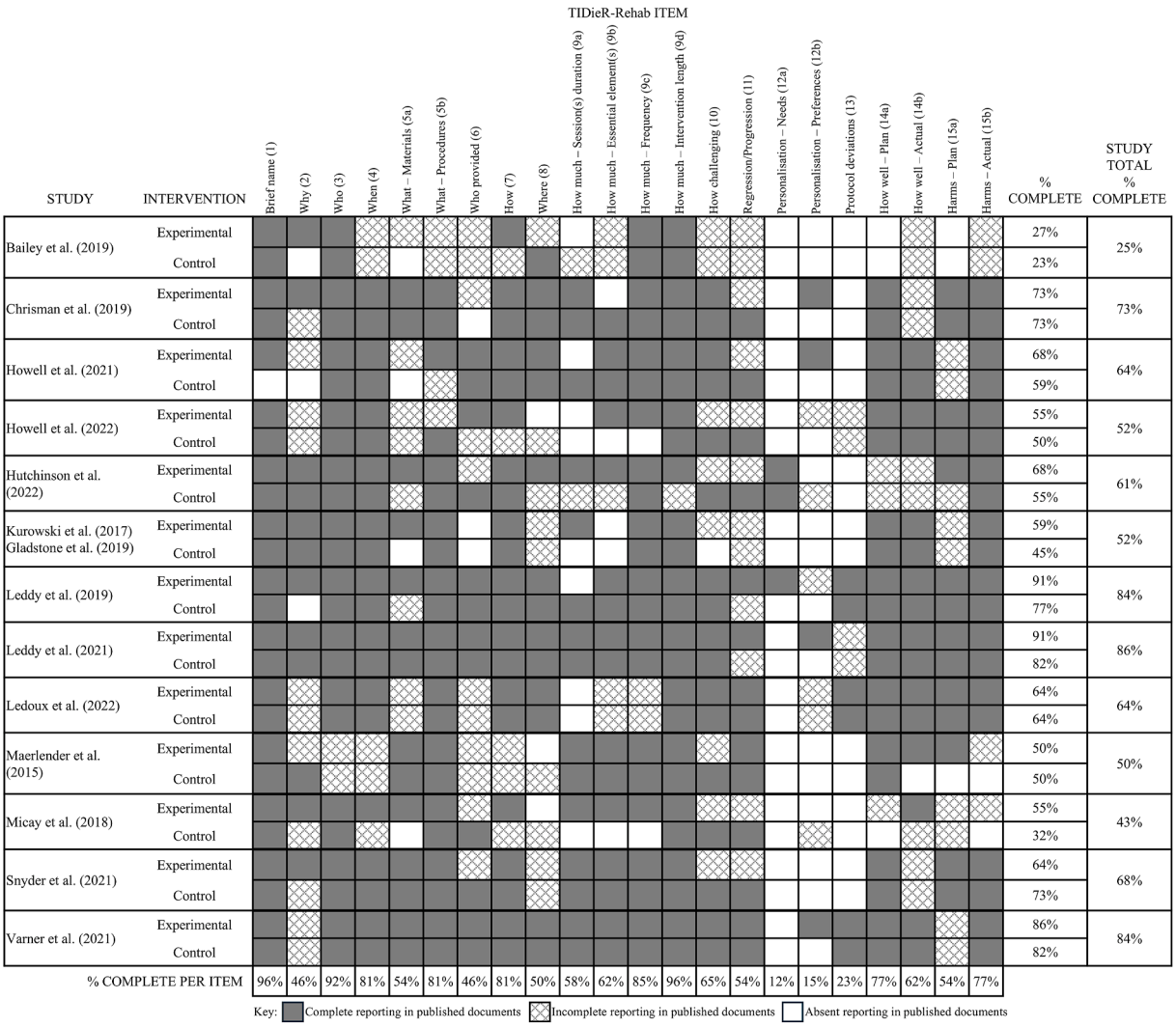

Fig. 2. Quality of reporting by TIDieR-Rehab item and intervention arm.

the TIDieR-Rehab checklist was the planning for regression if symptoms worsened ('Regression/Progression'), with only 54 % of the studies reviewed completely reporting how exercise was adjusted under these circumstances. Given that three studies reported symptom exacerbation with moderate-intensity exercise or sub-symptom aerobic exercise [45,49,50], the failure to report on how symptom exacerbation was managed is a significant barrier to safe and effective replication of aerobic exercise in both research and clinical settings.

Despite the importance of tailored and responsive aerobic exercise, TIDieR-Rehab items relating to personalisation and protocol deviations were particularly poorly reported. Personalisation to 'Needs' and 'Preferences' was completely reported in only 12 % and 15 % of interventions, respectively. Crucially, reporting of strategies used to address the needs of people with mTBI, such as accommodating cultural and linguistic diversity, supporting psychological well-being, or implementing environmental modifications to mitigate sensory overload, was absent. These omissions are significant, as these factors are often critical for effective engagement in aerobic exercise in this population. The most reported form of personalisation involved participants selecting their preferred mode of exercise, such as walking, jogging, or biking which reflects a focus on preferences rather than needs. Although person-centred care is a cornerstone of rehabilitation [54], the under-reporting of personalisation strategies may reflect an effort to reduce confounding factors in intervention protocols [55]. However, this omission undermines the accurate representation of rehabilitation practices and significantly impedes translation of research findings to clinical practice [55]. Personalisation may also occur reactively, addressing unforeseen patient needs during intervention delivery. In such cases, these adjustments should be routinely reported under 'Protocol deviations.' For instance, a protocol deviation might involve a reduction in the duration of aerobic exercise from 20 min to 10 min to accommodate a patient's pre-existing osteoarthritis. However, this review also found, 'Protocol deviations', were poorly reported (23 % complete). The failure to report both planned personalisation to 'Needs' and 'Preferences', and 'Protocol deviations' limits the understanding of intervention effectiveness and ultimately hinders the applicability of research findings to real-world clinical practice.

This review was the first to evaluate the reporting quality of control interventions in aerobic exercise trials for mTBI, revealing that control interventions were less comprehensively reported than experimental interventions (59 % versus 65 % complete, respectively). Quality reporting of control interventions is essential to accurately interpreting the effectiveness of the experimental intervention [15]. For instance, the 'usual care' control in Howell et al. [44] aligned with recent mTBI guidelines encouraging physical activity as tolerated, and this likely contributed to better outcomes than the control intervention used in Maerlender et al., [50] which discouraged activity until symptom free. Without clear reporting of such differences, the effect of an experimental

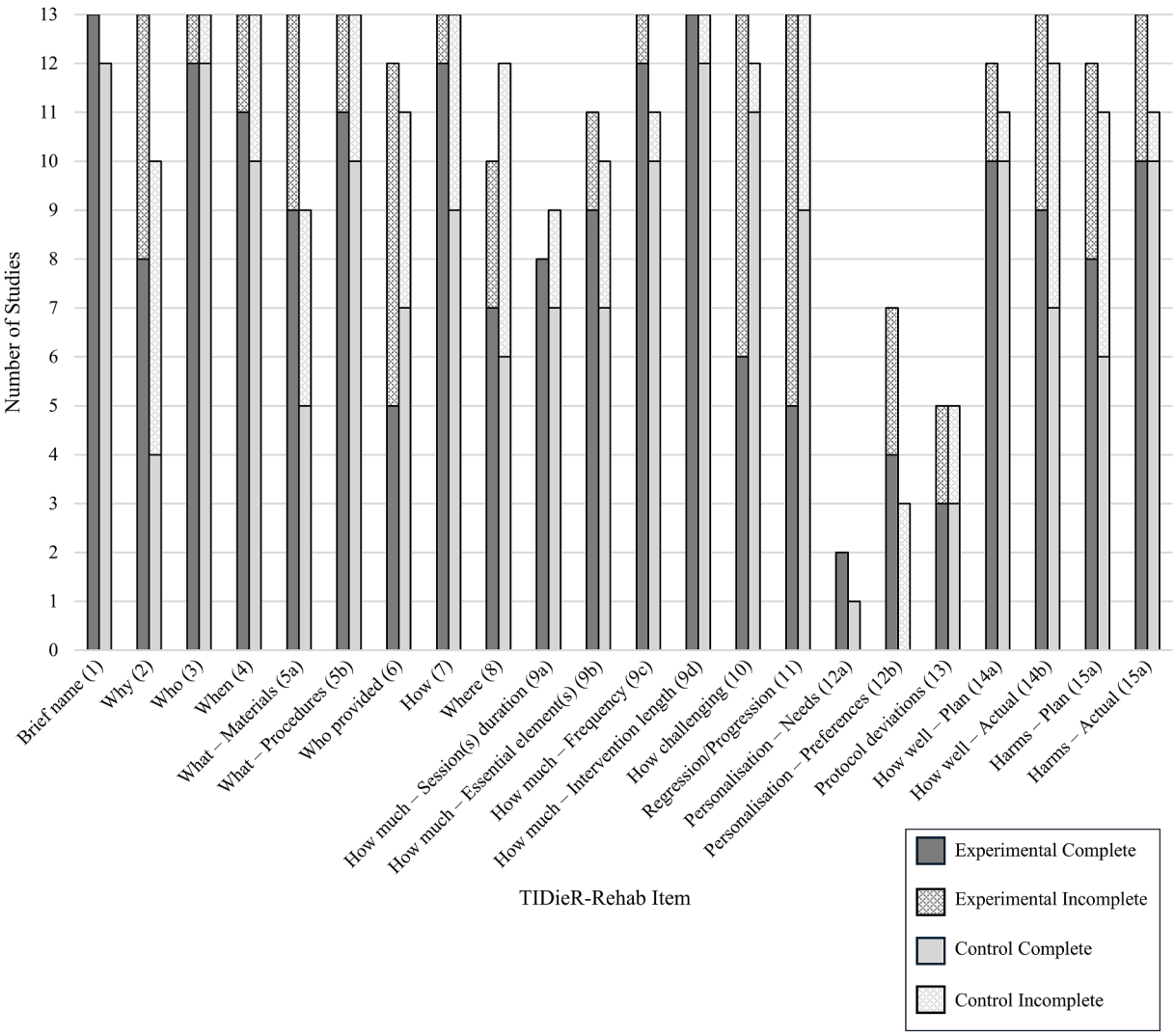

Fig. 3. Reporting of TIDieR-Rehab items for aerobic exercise and control interventions.

intervention may be over or underestimated and the use of essential elements remains ambiguous [56,57]. Furthermore, accurate reporting of control interventions ensures appropriate grouping in meta-analyses and allows for subgroup analyses to explore the influence of different control interventions on effect sizes [57]. The poor reporting of 'usual care' control interventions [17,43,44,47] in this review likely reflects the difficulty in documenting the full range of elements involved, such as accessing multidisciplinary public health services at the participants discretion. In these instances, reporting could be improved by providing summary statistics of services accessed and time spent with each.

4.1. Clinical implications

In addition to the impacts on research, poor reporting of dosage and personalisation elements has significant implications for clinical practice. Clinicians attempting to replicate the reviewed interventions may be left making 'educated guesses' about how to set or progress challenge targets, and how to allocate time to aerobic exercise versus preparatory activities such as warm-ups. Researchers should plan for and record personalisation and protocol deviations to ensure interventions reflect real-world clinical practice and to improve generalisability [8]. This could also enhance effectiveness, as treatment personalised to individuals' particular symptoms is thought to achieve better outcomes for those with mTBI [8,20]. Personalisation should also encompass return to play protocols that occur during the study period, as reported in two studies in this review [17,44]. Incorporating detailed reporting of personalisation and protocol deviations into future studies would bridge this gap, ensuring interventions better reflect the complexities of real-world practice.

4.2. Strengths and limitations

This review adhered to rigorous methodological procedures, including pre-registration, adherence to PRISMA guidelines, and the use of two independent researchers for article screening, data extraction, and TIDieR-Rehab ratings. The inclusion of a Table of Reference (Supplementary File C) specific to aerobic exercise interventions enhanced the clarity and consistency in the interpretation of the 22 TIDieR-Rehab items. This supporting document also provides guidance and examples that researchers can follow when reporting interventions within aerobic exercise mTBI trials. The review did not intend to assess the effectiveness of aerobic exercise or the risk of bias in included studies; an approach common in reviews focused on intervention reporting quality [58]. As previous research has not established any correlation between intervention reporting quality and risk of bias in this area [33], this review's findings cannot be used to interpret the methodological quality of the included studies.

4.3. Recommendations

To address the identified reporting gaps, researchers should adopt tools such as the TIDieR-Rehab checklist when planning and reporting their research [27,31,57]. The Table of Reference (Supplementary File C) developed in this review offers supplementary guidance specific to aerobic exercise interventions for mTBI. The findings of this review suggest complete documentation of all TIDieR-Rehab items should be achievable, as when contacted for further information, authors were able to supply, on average, 71 % of items that had not been fully reported in the published content, suggesting much of this information was accessible. One potential reason authors do not fully describe their interventions is journal word limits; however, this issue can be avoided by publishing protocol papers or using supplementary material [29]. A potential method to rapidly increase the quality of intervention reporting would be for publishers to require the use of intervention reporting checklists. Mandatory use of reporting checklists such as the PRISMA has resulted in improved methodological reporting [59] and expanding this approach to checklists such as the TIDieR-Rehab may elicit similar improvements in intervention reporting.

5. Conclusion

This systematic review is the first to examine the quality of reporting of aerobic exercise interventions following mTBI using the novel TIDieR-Rehab checklist. While some aspects of dosage were well reported, critical elements such as challenge parameters, regression protocols, and the distinction between session duration and duration of essential elements were often incompletely described. Additionally, intervention personalisation and protocol deviations were poorly addressed in the included literature. These reporting limitations impede replication and further exploration with meta-analysis. It is recommended that researchers utilise the TIDieR-Rehab checklist and the newly developed Table of Reference for mTBI aerobic exercise interventions when designing and reporting their studies, and that journal publishers consider mandating the use of appropriate intervention reporting checklists.

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Declaration of competing interest

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Appendix A. Supplementary data

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