Do physical interventions improve outcomes following concussion: a systematic review and meta-analysis?

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ABSTRACT
Objective To investigate the effect of physical interventions (subthreshold aerobic exercise, cervical, vestibular and/or oculomotor therapies) on days to recovery and symptom scores in the management of concussion.

Design A systematic review and meta-analysis.

Data sources Medline, CINAHL, Embase, SportDiscus, Cochrane library, Scopus and PEDro.

Eligibility criteria Randomised controlled trials of participants with concussion that evaluated the effect of subthreshold aerobic exercise, cervical, vestibular and/or oculomotor therapies on days to recovery/return to activity, symptom scores, balance, gait and/or exercise capacity.

Results Twelve trials met the inclusion criteria: 7 on subthreshold aerobic exercise, 1 on vestibular therapy, 1 on cervical therapy and 3 on individually tailored multimodal interventions. The trials were of fair to excellent quality on the PEDro scale. Eight trials were included in the quantitative analysis. Subthreshold aerobic exercise had a significant small to moderate effect in improving symptom scores (standardised mean difference (SMD)=0.43, 95% CI 0.18 to 0.67, p=0.001, I²=0%) but not in reducing days to symptom recovery in both acutely concussed individuals and those with persistent symptoms (SMD=0.19, 95% CI −0.54 to 0.93, p=0.61, I²=52%). There was limited evidence for stand-alone cervical, vestibular and oculomotor therapies. Concussed individuals with persistent symptoms (>2 weeks) were approximately 3 times more likely to have returned to sport by 8 weeks (relative risk=3.29, 95% CI 0.30 to 35.69, p=0.33, I²=83%) if they received individually tailored, presentation-specific multimodal interventions (cervical, vestibular and oculomotor therapy). In addition, the multimodal interventions had a moderate effect in improving symptom scores (SMD=0.63, 95% CI 0.11 to 1.15, p=0.02, I²=0%) when compared with control.

Conclusions Subthreshold aerobic exercise appears to lower symptom scores but not time to recovery in concussed individuals. Individually tailored multimodal interventions have a worthwhile effect in providing faster return to sport and clinical improvement, specifically in those with persistent symptoms.

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INTRODUCTION
Concussion is a common injury that is often poorly identified, under-reported and undermanaged. It is defined as a biomechanically induced traumatic brain injury from a direct blow to the head or a force transmitted indirectly from an impact to the body, resulting in a rapid onset of disruption to normal brain function, presenting as a range of clinical signs and symptoms. Although most adults recover in 14 days, 10%–30% of individuals have persistent symptoms, negatively affecting their quality of life. For these individuals, rehabilitation may facilitate recovery. Tailored interventions may also be beneficial in the early stages of concussion management; however, best practice guidelines are still in their infancy. Although the latest recommendations for early management recommend a brief period (24–48 hours) of cognitive and physical rest, followed by a stepwise return to physical activity, more recently there is emerging evidence for the use of physical interventions such as subthreshold aerobic exercise, cervical therapy, vestibular and/or oculomotor rehabilitation for individuals with ongoing concussion symptoms. Concussion presentations are often heterogeneous, the treatment complex and needs to address the large number of possible deficits and symptoms such as headache, dizziness, neck pain, imbalance, vestibular–oculomotor and cognitive impairments.

Following the previous systematic reviews, six new randomised controlled trials (RCTs) have been conducted and could add high-quality support for the use of physical interventions in order to improve patient outcomes. We aim to perform a systematic review with meta-analysis to synthesise the findings from similar individual studies, and derive conclusions about best practice for managing this complex condition. Therefore, the research questions for this systematic review were:

1. What is the effect of incorporating subthreshold aerobic exercise, cervical therapy, vestibular and/or oculomotor therapies into concussion management, for acute and ongoing symptoms?
2. What is the effect of incorporating such physical therapies as individually tailored, presentation-specific multimodal interventions into the acute and ongoing management of concussion?

METHODS
This review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines.

Data sources and searches
The following databases were searched: Medline, CINAHL, SportDiscus, PEDro, Cochrane library, Embase and Scopus, from inception to 5 September 2021.
2020 (online supplemental appendix 1). Appropriate search and MeSH terms were adapted and applied to each database, with the help of the University research librarian. To supplement the initial database searches, a manual search of the references listed in identified systematic reviews was also conducted.

Eligibility criteria
We included RCTs evaluating the effects of physical therapies on recovery following concussion, either acute or ongoing, sustained from any cause (box 1).

Subthreshold exercise was defined as exercise at 80%–90% of the heart rate, where symptoms were exacerbated. The search was limited to human trials published in English only. Exclusion criteria were articles published in abstract form. Duplicate studies identified as a result of searching multiple databases were removed using EndNote VX8 software. The titles and abstracts were screened by two assessors independently (JF and SM), according to predetermined eligibility criteria. Full text articles were assessed and if there was uncertainty over the inclusion of a study, a third reviewer (SAR) was consulted until consensus was reached.

Quality assessment and data extraction
Data extracted from the full text articles included sample size, mean age of participants, gender, acute or persistent presentation, interventions, outcomes and results.

The quality of individual studies was assessed using the PEDro scale, an 11-item scale designed for rating the methodological quality of RCTs to discriminate between high-quality and low-quality trials. Items address the internal validity based on factors such as random allocation and concealment, baseline variables, blinding, outcomes obtained at baseline and intention to treat analysis, and whether the trial contains sufficient statistical information to make it interpretable.25 Total PEDro scores of 0–4 are considered ‘poor’, 4–5 ‘fair’, 6–8 ‘good’ and 9–10 ‘excellent’.26

PEDro scores published on the PEDro database (www.pedro.org) were extracted for all available studies.

Data synthesis
The trials were compared for homogeneity (online supplemental table 1). Trials were grouped according to the type of intervention used (ie, exercise, vestibular, cervical or multimodal) and according to outcome measures (ie, symptom scores or days to recovery).

Meta-analysis
Meta-analysis was performed using Review Manager V.5.3 software (Cochrane Collaboration) (RevMan). Meta-analysis was performed when more than one study could be grouped for type of intervention (exercise, vestibular, cervical or multimodal) and according to outcome measures (symptom scores or days to recovery). If there was only one study in the group, then meta-analysis could not be performed and the statistics from that single study were reported. Concussed patients receiving a sham, or no intervention, were considered to be control. Standardised mean differences (SMDs) and 95% CI were calculated when outcomes were measured on different scales for continuous data, and risk ratio and 95% CIs were calculated for dichotomous variables. Post-scores were used in the RevMan analysis rather than change scores as several studies did not provide change scores or enough information to establish them.

The I² statistic, an expression of inconsistency of studies’ results, was calculated to describe the percentage of variation across studies because of heterogeneity rather than by chance. A random-effects model was used for outcomes where studies differed in their measuring tool and a fixed-effects model when studies used the same measuring tool. Interpretation of effect size was determined using Cohen’s criteria for pooled estimates, with an SMD of 0.2–0.4, considered a small effect size, 0.5–0.7, moderate, and 0.8 or higher, a large effect size.27

RESULTS
Study selection, risk of bias and characteristics
The electronic database search initially identified 2977 articles (figure 1), duplicates were then removed, and records screened. Thirty eight full texts were reviewed for eligibility, of which 12 trials met the eligibility criteria. A total of 647 participants (aged: 12–54 years) were included in this systematic review. Three trials reported on adults,21 22 28 six on adolescents,16–20 23 two on both adolescents and adults19 30 and one did not report the age of participants.24 Of these 12 trials, 9 trials assessed standardised treatment protocols of stand-alone interventions of subthreshold aerobic exercise, cervical or vestibular therapy. Seven of these trials evaluated subthreshold aerobic exercise,17–19 21 23 24 29 one stand-alone cervical therapy28 and one stand-alone vestibular therapy.22 The other three studies16 21 30 assessed the effect of multimodal management, which combined multiple types of intervention, including cervical, vestibular and/or oculomotor therapies, individually targeting the patient’s symptoms and objective findings. Four of the 12 trials included participants with acute concussion symptoms and eight included those with persistent symptoms, in excess of 2 weeks.

Characteristics of the 12 included trials are summarised in online supplemental table 1.

All twelve RCTs had been scored by PEDro so the scores were extracted from the PEDro database (www.pedro.org) (table 1). One study was considered to be of poor quality,21 four of fair quality17 18 28 29 and seven were of good to excellent quality.16 19–23 30 The majority of trials randomly allocated participants (100%), reported between group statistics (100%), reported point measures and variability (92%) and listed...
eligibility criteria (92%), had similar groups at baseline (75%) and blinded assessors (67%). Most trials did not make use of intention-to-treat analysis (only 33%) or conceal allocation to group (only 42%). None of the trials blinded subjects or therapists, as this was not possible for the intervention.

**Meta-analysis**

Not all information was readily available in the studies. The numerical data or extra information were requested from and supplied by three author groups (Micay et al., Leddy et al., and Reneker et al.). The studies by Relander et al. and Maerlender et al. did not provide sufficient data to be included in the meta-analysis. Meta-analysis could not be performed for cervical and vestibular interventions, as there was only one study assessing each intervention. A random-effects model was used for all outcomes, as in most instances the measurement tool was different or there was high heterogeneity of >50%.

**Effect of subthreshold aerobic exercise**

Effect of subthreshold exercise on days to symptom recovery/return to activity:

Two trials evaluating the effect of subthreshold aerobic exercise on days to symptom recovery/return to activity could be grouped for meta-analysis (figure 2). Both trials assessed participants with acute (≤2 weeks) concussion presentations. The results of our meta-analysis indicate there was no evidence of a difference in days to symptom recovery between those receiving exercise and controls (SMD=0.19, 95% CI −0.54 to 0.93, p=0.61, I²=52%). An SMD was used as the trials differed in their definition of days to recovery: Leddy et al. evaluated recovery time using the number of days from the time of injury to the third consecutive day in which the individual’s Post-Concussion Symptoms Scale (PCSS) fell below 7. Micay et al. determined recovery time by reviewing each participant’s medical record for their return to play status (in days). Although Maerlender et al. study of acutely concussed individuals was not included in the meta-analysis, their results also showed no significant effect of subthreshold aerobic exercise on days to symptom recovery, with individuals performing 20 min/day on a stationary bicycle having a mean recovery time of 15 days, compared with those performing normal activities recovering in 13 days. However, Relander et al. studied acutely concussed individuals who received additional physical training twice a week required a mean of 17.7 days off work while the controls had 32.2 days off.
but an increase of 1.9 (SD=13.2) for those receiving cold packs. However, a change of 3.2 on a 100-point scale was not considered to be clinically significant.

**Vestibular therapy**
Kleffelgaard et al. evaluated the effectiveness of vestibular therapy alone on symptom scores in individuals with persistent symptoms. These included dizziness or balance concerns and targeted concussed patients with positive vestibular findings. Therapy included group and individually tailored exercises. The authors found a significant difference favouring vestibular therapy over no intervention for the Dizziness Handicap Inventory (DHI: 0 = best to 100 = worst) (−8.7; 95% CI −16.6 to −0.9; p=0.03), but not for the Vertigo Symptom Scale–Short Form (0 = best to 60 = worst) (−2.1; 95% CI −4.5 to −0.2; p=0.08) or the RPSQ (0 = best to 64 = worst) (−0.5; 95% CI −1.8 to −0.7; p=0.41). This high-quality study used the Balance Error Scoring System (BESS) (0 = best to 60 = worst) and found the mean difference of −3.7 (95% CI −7.8 to −0.5; p=0.09) between those receiving group-based vestibular rehabilitation to no treatment.

No identified trials investigated the effect of oculomotor therapy alone.

**Effect of individually tailored multimodal therapy on return to sport**
Two high-quality trials of participants with persistent symptoms were grouped for meta-analysis evaluating the effect of presentation-specific, individually tailored multimodal interventions on clearance to return to sport. The interventions included cervical, vestibular and/or oculomotor therapies. Reneker et al. reported that 18/22 (82%) in the intervention group and 11/19 (58%) had medical clearance to return to sport after a 35-day intervention programme that was commenced 10 days post injury. Those in the intervention group recovered from their symptoms 1.99 (95% CI 0.95 to 4.15) times faster and were medically cleared for return to sport 2.91 (95% CI 1.01 to 8.43) times faster than the control group that received a range of subtherapeutic treatments. Schneider et al. found that those in the intervention group were 3.91 (95% CI 1.34 to 11.34) times more likely to be medically cleared for return to sport in 8 weeks than those in the control group (figure 4). Meta-analysis of these two studies found the risk ratio for return to sport by 8 weeks was 3.29 (95% CI 0.30 to 35.69, I²=83%) (figure 4).

**Effect of individually tailored multimodal therapy on symptom scores**
Three studies of concussed individuals with persistent symptoms measured the effect of individually tailored multimodal interventions that included cervical, vestibular and/or oculomotor therapies on symptom scores. Meta-analysis showing a significant moderate effect (SMD=0.63, 95% CI 0.11 to 1.15, p=0.02, I²=0%) (figure 5). The study by Schneider et

### Table 1: Quality assessment of trials using the PEDro scale for methodological quality

<table>
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<tr>
<th>PEDro item</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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<th>6</th>
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<th>9</th>
<th>10</th>
<th>11</th>
<th>PEDro score</th>
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<td>Chan et al.</td>
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<td>Y</td>
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<td>Chrisman et al.</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
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<td>Y</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N</td>
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**Pedro scale item:** (1) eligibility criteria specified, (2) random allocation, (3) concealed allocation, (4) group characteristics similar at baseline, (5) blinding of subjects, (6) blinding of therapists, (7) blinding of assessors, (8) less than 15% dropouts, (9) intention-to-treat analysis, (10) between-group statistical comparisons and (11) point measures and variability data. PEDro scores of 0–4 are considered ‘poor’, 4–5 ‘fair’, 6–8 ‘good’ and 9–10 ‘excellent’.

### Effect of subthreshold aerobic exercise on symptoms scores
Five trials included in the meta-analysis reported on the effect of subthreshold aerobic exercise on symptoms scores. Symptom outcome measures employed in these trials (figure 3) included the PCSS (0 = best to 126 = worst), the Post-Concussion Symptom Inventory (0 = best to 72 = worst), the Rivermead Post-concussion Symptoms Questionnaire (RPSQ: 0 = best to 64 = worst) and the Health Behaviour Inventory (0 = best to 60 = worst). Reassessments were conducted by Leddy et al. and Micay et al. at 4 weeks, Chrisman et al. at 6 weeks, Kurowski et al. at 7 weeks and Ryther et al. at 24 weeks. On meta-analysis, the results favoured exercise with an SMD of 0.43 (95% CI 0.18 to 0.67, p=0.001, I²=0%) (figure 3). Separating these trials into acute (≤2 weeks) and persistent (>2 weeks) presentations also favoured exercise, with a moderate effect for persistent SMD of 0.46 (95% CI 0.13 to 0.80, p=0.006, I²=0%) (online supplemental figures 1 and 2).

### Effect of cervical, vestibular and/or oculomotor therapies

**Cervical therapy**
Jensen et al. assessed the effect of cervical therapy alone on individuals with persistent symptoms post-concussion that included headache. Treatment was based on findings from their cervical manual examination. The trial was of fair methodological quality. They found a significant difference after 6 weeks on the Visual Analogue Scale (VAS: 0 = best to 100 = worst) with a decrease in pain of 3.2 (SD=14.5) for the manual therapy group but an increase of 1.9 (SD=13.2) for those receiving cold packs. However, a change of 3.2 on a 100-point scale was not considered to be clinically significant.

### Effect of individually tailored multimodal therapy on return to sport
Two high-quality trials of participants with persistent symptoms were grouped for meta-analysis evaluating the effect of presentation-specific, individually tailored multimodal interventions on clearance to return to sport. The interventions included cervical, vestibular and/or oculomotor therapies. Reneker et al. reported that 18/22 (82%) in the intervention group and 11/19 (58%) had medical clearance to return to sport after a 35-day intervention programme that was commenced 10 days post injury. Those in the intervention group recovered from their symptoms 1.99 (95% CI 0.95 to 4.15) times faster and were medically cleared for return to sport 2.91 (95% CI 1.01 to 8.43) times faster than the control group that received a range of subtherapeutic treatments. Schneider et al. found that those in the intervention group were 3.91 (95% CI 1.34 to 11.34) times more likely to be medically cleared for return to sport in 8 weeks than those in the control group (figure 4). Meta-analysis of these two studies found the risk ratio for return to sport by 8 weeks was 3.29 (95% CI 0.30 to 35.69, I²=83%) (figure 4).

### Effect of individually tailored multimodal therapy on symptom scores
Three studies of concussed individuals with persistent symptoms measured the effect of individually tailored multimodal interventions that included cervical, vestibular and/or oculomotor therapies on symptom scores. Meta-analysis showing a significant moderate effect (SMD=0.63, 95% CI 0.11 to 1.15, p=0.02, I²=0%) (figure 5). The study by Schneider et
d\textsuperscript{16} showed participants receiving the active intervention who were cleared to return to sport in 8 weeks (n=11) had a reduction in symptoms (out of 22) of −12 (−22, 0), while those not cleared to return to sport (n=4) had a change of −5.5 (−11, −2). Those individuals receiving the control intervention who were cleared to return to sport (n=1) had a change score of −15, while those not cleared (n=13) had a change score of −8.5 (−22, 3).

Two RCT\textsuperscript{16 30} assessed balance using the BESS and the Activities-specific Balance Confidence Scale. Schneider et al\textsuperscript{30} compared multimodal interventions to sham treatments and found greater improvements in balance in the intervention group. However, as the data were presented with subgrouping, it could not be incorporated into meta-analysis. Chan et al\textsuperscript{16} reported improvements in balance in both intervention and control groups. Statistical between-group analysis was not performed, and they used the data for exploratory and descriptive purposes only.

Schneider et al\textsuperscript{30}’s study was the only identified study to assess gait. Using the Functional Gait Assessment, no difference in gait occurred between groups.

None of the identified trials assessed exercise capacity.

**DISCUSSION**

Physical interventions such as subthreshold aerobic exercise or individually tailored multimodal interventions that target deficits reduce symptoms in concussed individuals with acute and persistent symptoms. The multimodal approach leads to a faster return to sport for those with persistent symptoms. This systematic review identified 12 trials with 647 participants providing large amounts of data to guide practitioners in managing concussion. Given the diversity of interventions, there is evidence of a positive outcome. This multimodal collaborative care, including cervical, vestibular and oculomotor rehabilitation that is tailored to the patient’s presentation, there is evidence of a positive outcome. This multimodal treatment approach was individually prescribed for each participant based on objective findings and symptoms from assessment of the cervical spine, balance and the oculomotor and vestibular systems. All included studies of individually tailored multimodal interventions had participants with persistent symptoms.

We provide evidence from two trials\textsuperscript{20 30} that individually tailored multimodal interventions incorporating cervical, vestibular and/or oculomotor therapies offer individuals a greater chance of earlier return to activity. The study by Reneker et al\textsuperscript{30} (n=41) showed that the intervention group recovered twice as fast from their symptoms and were cleared to return to sport compared with the control group.

**Effect of individually tailored multimodal intervention**

Although there was limited evidence for stand-alone cervical\textsuperscript{20} or vestibular therapy\textsuperscript{22} when it was incorporated into multimodal collaborative care, including cervical, oculomotor and vestibular rehabilitation that is tailored to the patient’s presentation, there is evidence of a positive outcome. This multimodal treatment approach was individually prescribed for each participant based on objective findings and symptoms from assessment of the cervical spine, balance and the oculomotor and vestibular systems. All included studies of individually tailored multimodal interventions had participants with persistent symptoms.

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**Effect of subthreshold aerobic exercise**

Subthreshold exercise is exercise at 80%–90% of the heart rate, where symptoms were exacerbated. Subthreshold aerobic exercise had a small to moderate effect (SMD=0.43) in reducing symptoms after a concussion; however, this estimate comes with some uncertainty. The 95%CI shows this could vary from a small effect (0.18) to a large effect (0.67). The findings show a small to moderate effect for those with both acute and persistent concussion presentations. This analysis does establish that, at worst, subthreshold aerobic exercise has only a small effect in reducing symptoms, but importantly it shows that subthreshold aerobic exercise does not make symptoms worse in both acute and persistent concussion, which to date has been somewhat unknown.

This review found no evidence of a difference in days to symptom recovery between those receiving exercise and the comparison group. Although Leddy et al’s\textsuperscript{18} larger trial found exercise reduced days to recovery, the smaller study by Micay et al\textsuperscript{19} found the control group (following the Berlin guidelines of graded return to sport) were cleared a few days earlier. This result was supported by Maerlender et al\textsuperscript{24} who also found those completing daily activities recovered 2 days quicker than those exercising. The intensity of exercise for the intervention group in the trial by Micay et al\textsuperscript{19} (50%–70% age predicted HR max) and Maerlender et al\textsuperscript{24} (mild to moderate exertion) may not have been sufficiently high as Leddy et al\textsuperscript{18} used 80% of HR which was progressively increased. Also, the comparator used in the Micay et al’s\textsuperscript{19} study (progressive return to activity) may have had a positive effect. Since the larger study by Leddy et al\textsuperscript{18} had a positive effect, more large studies are needed to investigate this further.

A previous systematic review with meta-analysis by Lal et al\textsuperscript{7} found exercise significantly decreased PCSS (mean difference=−13.06; 95%CI −16.57 to −9.55) and symptoms as well as days off work (17.7 days vs 32.2 days), compared with control.

**Effect of individually tailored multimodal intervention**

Although there was limited evidence for stand-alone cervical\textsuperscript{20} or vestibular therapy\textsuperscript{22} when it was incorporated into multimodal collaborative care, including cervical, oculomotor and vestibular rehabilitation that is tailored to the patient’s presentation, there is evidence of a positive outcome. This multimodal treatment approach was individually prescribed for each participant based on objective findings and symptoms from assessment of the cervical spine, balance and the oculomotor and vestibular systems. All included studies of individually tailored multimodal interventions had participants with persistent symptoms.

We provide evidence from two trials\textsuperscript{20 30} that individually tailored multimodal interventions incorporating cervical, vestibular and/or oculomotor therapies offer individuals a greater chance of earlier return to activity. The study by Reneker et al\textsuperscript{30} (n=41) showed that the intervention group recovered twice as fast from their symptoms and were cleared to return to sport compared with the control group.

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**Figure 3** Effect of exercise vs control on symptom scores.

**Figure 4** Effect of individually tailored, presentation-specific multimodal management vs control on days to symptom recovery/return to activity.
three times faster than the controls, but this also ranged from no different to eight times faster. This study is backed up by the very promising RCT by Schneider et al. where individuals who received the multimodal intervention were four times more likely to be cleared to return in 8 weeks compared with the control group. The weakest estimate was 34% more likely to return to sport while the greatest effect was very worthwhile, being 11 times more likely. Combining this in our meta-analysis found concussion players to be three times more likely to have returned to sport by 8 weeks with this intervention. However, due to the high heterogeneity across the two studies ($I^2=83\%$) in their definitions of recovery, the meta-analysis results are not significant.

In summary, our review adds to the existing body of evidence and is in agreement with the findings of the systematic review by Schneider et al., which supports multifaceted collaborative care, including light subthreshold aerobic exercise, cervical and vestibular rehabilitation.

**Strengths and limitations**

Since the previous systematic reviews, there are six new RCTs of fair to excellent quality adding support to the evidence for physical interventions improving outcomes following concussion. Four of these add evidence for the benefits of subthreshold aerobic exercise and two for individually tailored multimodal care. By performing a meta-analysis, we were able to combine primary studies, which increased the sample size, and in turn, the power to study the effect of these interventions by combining similar primary studies and providing a precise estimate of the effects. The low $I^2$ values and the absence of heterogeneity for some of the analyses give credibility to our data.

The interventions that were found to be effective could easily be incorporated into clinical practice. Subthreshold aerobic exercise is feasible and affordable for participants. The multimodal approach may require some training of therapists to assess and identify cervical, vestibular and oculomotor deficits.

A limitation of the review was the small number of studies for certain interventions and the inclusion of trials with small sample sizes. With small sample sizes, resulting sampling error may lead to bias in pooled estimates of SMD and risk ratio. There is a possibility that data may be skewed and thus results should be interpreted with caution. There is a need for larger sample sizes of future studies to remove potential issues resulting from this. A limitation of individual studies was that some risk ratio and interval estimates in some studies such as Schneider et al. suggest the possibility of sparse data bias and further highlights the need for studies with larger sample sizes to be undertaken. If change scores were available rather than post scores, it would have provided more compelling evidence of the effect of the interventions. A limitation of this study is that no assessment of heterogeneity or publication bias was performed due to small number of studies. However, we performed a thorough search of different databases and a hand search of articles to find any studies we may have missed.

Further research is needed to evaluate these physical therapies and determine the optimal duration and timing of treatment, as well as combinations of therapies that are most effective. Future high-quality trials need to be large to reduce sampling bias and should ensure similar baseline characteristics, such as time, since onset. This may also allow for further subgroup analyses to be conducted between acute versus persistent presentations, as well as sex and age as factors influencing the outcomes of the interventions.

**CONCLUSION**

This clinically relevant research provides level one evidence, which could direct the optimal management of individuals following concussion. Subthreshold aerobic exercise shows a moderate effect in lowering symptom scores, however, that estimate comes with some uncertainty. Importantly, subthreshold aerobic exercise (at 80%–90% of the heart rate, where symptoms were exacerbated) does not make symptoms worse in those presenting both acutely and with persistent symptoms. Individually tailored multimodal intervention has a worthwhile effect in providing a faster return to sport and decreasing symptoms in those with persistent symptoms.

**Twitter** Sheya McLeod @SMcLeod_PT

**Contributors** All authors contributed to the development of the search strategy, writing and critical review of the manuscript. JF and SM undertook the process of inclusion/exclusion and independently assessed methodological quality. JF extracted all data from the included studies, SM and SAR confirmed the accuracy of this.

---

**What is already known**

- Rest for 24–48 hours followed by a graded return to activity is currently recommended.
- There is some evidence supporting physical interventions in the management of concussion, including subthreshold aerobic exercise and multimodal care involving light exercise, cervical therapy, vestibular and/or oculomotor rehabilitation.

**What are the new findings**

- Subthreshold aerobic exercise has a small to moderate effect on lowering symptom scores in acutely concussed individuals and those with persistent symptoms.
- Subthreshold aerobic exercise (at 80%–90% of the heart rate where symptoms were exacerbated) does not increase symptom scores when used to treat people with acute or persistent concussion.
- Concussed individuals with persistent symptoms (>2 weeks) who receive individually tailored multimodal interventions (cervical, vestibular and oculomotor) have a reduction in symptoms and are 3 times more likely to have returned to sport by 8 weeks.
Review

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Competing interests None declared.

Patient consent for publication Not applicable.

Provenance and peer review Not commissioned; externally peer reviewed.

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REFERENCES
On line supplementary material

Search Strategy

**Appendix 1. Databases and search terms**

<table>
<thead>
<tr>
<th>Database</th>
<th>Search terms</th>
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<tbody>
<tr>
<td>MEDLINE</td>
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<tr>
<td></td>
<td>• (MeSH terms: brain concussion OR postconcussion syndrome) OR (Key terms in title OR abstract: concuss* or &quot;mild traumatic brain injury&quot; or mTBI or post#concuss*)</td>
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<tr>
<td></td>
<td>• (MeSH terms: Physical Therapy Modalities OR Rehabilitation OR Exercise OR Exercise Therapy OR Musculoskeletal Manipulations) OR (key terms in title OR abstract: physiotherap* OR ((therap* or rehab* or intervention) and (cervical or manual or vestibul* or oculomotor or exercise)))</td>
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<td>CINAHL</td>
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<td></td>
<td>• (MeSH terms: brain concussion OR postconcussion syndrome) OR (Key terms in title OR abstract: concuss* or &quot;mild traumatic brain injury&quot; or mTBI or post#concuss*)</td>
</tr>
<tr>
<td></td>
<td>• (MeSH terms: Physical Therapy OR Physical Therapy Practice, Research-Based OR Research, Physical Therapy OR Physical Therapy Practice, Evidence-Based OR Physical Therapy Practice OR Rehabilitation OR Early Intervention OR Intervention Trials OR Experimental Studies OR Exercise OR Therapeutic Exercise OR Manual Therapy) OR (key terms in title OR abstract: physiotherap* OR ((therap* or rehab* or intervention) and (cervical or manual or vestibul* or oculomotor or exercise)))</td>
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<td>SPORTDiscus</td>
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<td>PEDro</td>
<td>concussion</td>
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<tr>
<td></td>
<td>• (MeSH terms: Physical Therapy OR Physical Therapy Practice, Research-Based OR Research, Physical Therapy OR Physical Therapy Practice, Evidence-Based OR Physical Therapy Practice OR Rehabilitation OR Early Intervention OR Intervention Trials OR</td>
</tr>
</tbody>
</table>
**EMBASE**

The following 2 searches were combined with AND:
- (Map terms: concussion OR brain concussion OR postconcussion syndrome) OR (Key terms in title OR abstract: concuss* or "mild traumatic brain injury" or mTBI or post#concuss*)
- (Map terms: physiotherapy OR physiotherapy practice OR rehabilitation OR early intervention OR intervention study OR exercise OR aerobic exercise OR manipulative medicine) OR (key terms in title OR abstract: physiotherap* OR ((therap* or rehab* or intervention) and (cervical or manual or vestibul* or oculomotor or exercise)))

**Scopus**

The following 2 searches were combined with AND:
- Title-abstract-keyword: concuss* or "mild traumatic brain injury" or mTBI or post#concuss*
- Title-abstract-keyword: physiotherap* OR ((therap* or rehab* or intervention) and (cervical or manual or vestibul* or oculomotor or exercise))

---

**Supplementary Figure 6. Effect of exercise vs. control on symptom scores in acute presentations (≤ 2 weeks)**

<table>
<thead>
<tr>
<th>Study or Subgroup</th>
<th>Control</th>
<th>Intervenion</th>
<th>Std. Mean Difference IV, Random, 95% CI</th>
<th>Year</th>
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<td></td>
<td>Mean</td>
<td>SD</td>
<td>Total</td>
<td>Mean</td>
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<tr>
<td></td>
<td>2018</td>
<td>6.43</td>
<td>14.3</td>
<td>39</td>
</tr>
<tr>
<td>Total (95% CI)</td>
<td>37</td>
<td>400.0%</td>
<td>6.52 [0.83, 1.08]</td>
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</table>

Test for overall effect Z = 2.10 (P = 0.034)

---

**Supplementary Figure 7. Effect of exercise vs. control on symptom scores in persistent presentation (> 2 weeks)**

<table>
<thead>
<tr>
<th>Study or Subgroup</th>
<th>Control</th>
<th>Intervenion</th>
<th>Std. Mean Difference IV, Random, 95% CI</th>
<th>Year</th>
</tr>
</thead>
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<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Total</td>
<td>Mean</td>
</tr>
<tr>
<td></td>
<td>2017</td>
<td>15.00</td>
<td>20.18</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>2019</td>
<td>14.09</td>
<td>12.32</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>2019</td>
<td>27.5</td>
<td>4.09</td>
<td>44</td>
</tr>
<tr>
<td>Total (95% CI)</td>
<td>70</td>
<td>100.0%</td>
<td>0.35 [0.62, 0.07]</td>
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</tbody>
</table>

Test for overall effect Z = 2.00 (P = 0.041)

---
<table>
<thead>
<tr>
<th>Study</th>
<th>Participants</th>
<th>Intervention</th>
<th>Control</th>
<th>Relevant Outcome measures</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Exercise</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Chrisman et al.¹⁷ | n = I = 19, C = 11 | Sub-threshold aerobic exercise (exercise bike, treadmill, fast walking up an incline/stairs, or calisthenics): 5-10mins per day, increased weekly by 5-10mins per day, goal of 60min/day. | Stretching: 5-10mins daily. 6 weeks. | HBI | HBI: mean±SD  
I: pre = 31.21±14.10, post = 10.21±11.59  
C: pre = 28±10.02, post = 14.09±13.32  
Change in HBI baseline to 6 weeks: mean±SD:  
I:-21±15.8  
C: 13.9±12.1 |
| Kurowski et al.²³ | n = I = 12, C = 14 | Subsymptom aerobic training: Cycling HEP for 6 weeks. 5-6 days/week. 80% of duration that exacerbated symptoms Progressed according to weekly visits. | Full body stretching HEP for 6 weeks. 5-6 days/week. Upper + lower extremities + trunk Program rotated every 2 weeks. Reviewed at weekly visits. | PCSI (self and parent assessment) | Self-PCSI: mean±SD  
I: pre= 37.40±25.01, post= 4.17±7.36  
C: pre= 40.27±27.25, post= 15.93±20.18  
Parent-PCSI: mean±SD  
I: pre= 38.93±15.13, post= 9.50±19.11  
C: pre= 46.93±25.22, post= 10.79±13.33 |
| Leddy et al.²⁰ | n = I = 52, C = 51 | Aerobic exercise: -stationary bike or treadmill (or jog/walk) -20 minutes daily -80% of HR that exacerbates symptoms on BCTT -progressed each week based on BCTT retest | Full body stretching: -20 minutes daily -progressed each week based on BCTT retest | Days to recovery since date of injury. | Days to recovery: mean±SD  
I: 15.56±8.95  
C: 21.14±14.90  
PCSS: mean±SD  
I: pre = 30.79±16.46, post = 1.08±3.91, change = 29.71±15.04  
C: pre = 33.33±19.74, post = 5.47±16.34, change = 27.86±17.93 |
| Maerlender et al.²¹ | n = I = 13, C = 15 | Exertion protocol: -Schwinn Airdyne stationary bicycle with mild to moderate (0-6 RPE) exertion -20 minutes daily | Standard protocol: -instructed not to engage in systematic exertion beyond normal activities required for school (walking to class, studying, etc.) | Days to symptom recovery | Days to symptom recovery: median (range)  
I: 15 (5-61)  
C: 13 (6-56) |
<table>
<thead>
<tr>
<th>Study</th>
<th>n</th>
<th>Sex</th>
<th>Age (mean±SD)</th>
<th>Presentation</th>
<th>Exercise Protocol</th>
<th>Treatment</th>
<th>Recovery</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Micay et al. 29</td>
<td>I = 8, C = 7</td>
<td>15M</td>
<td>I: 15.8±1.2, C = 15.6±1.0</td>
<td>acute</td>
<td>Aerobic exercise: - 8 sessions: exercise on 2 consecutive days followed by 1 rest day for a total of 11 days - Stationary cycle ergometer - 1st session: 10 mins at 50% age-predicted HR max - 2nd session: 20 mins at 50% age-predicted HR max - then progressed by 5% increases of age-predicted HR max up to 70% and then maintained - 5 min warm-up and cool-down</td>
<td>Standard concussion management protocol as per Berlin 2016 guidelines.</td>
<td>Days to medical clearance: PCSS I: 36.1±18.5 C: 29.6±15.8</td>
<td>Days to medical clearance: mean±SD I: 36.1±18.5 C: 29.6±15.8</td>
</tr>
<tr>
<td>Relander et al. 28</td>
<td>N = I = 82, C = 96</td>
<td>NR</td>
<td>23% &lt; 21, 57% 21-50, 11% 51-65, 9% &gt;65</td>
<td>acute</td>
<td>Active management: - encouraged to mobilise as early as possible - physiotherapy: physical training 2/week until end of treatment → d/c from hospital - encouraged to attend follow-up clinics with same doctor after treatment completion</td>
<td>Routine treatment: - allowed to mobilise but not encouraged - provided with information about their injury when they asked for it. - no arrangement to see same doctor at follow-up clinics</td>
<td>Days in hospital: mean I: 6.6 C: 7.6</td>
<td>Days in hospital: mean I: 6.6 C: 7.6</td>
</tr>
<tr>
<td>Rytter et al. 23</td>
<td>n = I = 45, c = 44</td>
<td>30M:59F</td>
<td>I: -18-29: 12 -30-43: 21 -44+: 12 C: -18-29: 12 -30-43: 24 -44+: 8</td>
<td>persistent</td>
<td>S-REHAB Module 1: 12 weeks - 12–14 individual sessions (1–2 hr/week) with a neuropsychologist - 24 hr group therapy (2hr/week) combining psychoeducation, small exercises and conversations - 33 hr (2–3 hr/week) of individual exercise training and coaching by a physiotherapist. Followed by Module 2: 10 weeks - 10 individual consultation sessions (1 hr/week) with a neuropsychologist - 16 hr of group work (1.5 hr/week) combining group exercises and conversations</td>
<td>Standard Care: - May have received no or very limited treatment</td>
<td>RPSQ</td>
<td>RPSQ: mean±SD I: post = 32.29±14.18 C: post = 37.50±8.48</td>
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<td></td>
<td>Change in RPSQ at 6 months (mean ±SD): I: 29.69 ± 12.92 C: 35.30 ± 7.57</td>
<td></td>
</tr>
<tr>
<td>Therapy Type</td>
<td>Description</td>
<td>Participants</td>
<td>Outcome Measures</td>
<td>Results</td>
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<tr>
<td>Cervical therapy</td>
<td>10.5 hr (1 hr/week) of individual exercise training with a physiotherapist</td>
<td>n = I = 10, C = 9</td>
<td>Pain index</td>
<td>Pain index: mean±SD</td>
<td></td>
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<tr>
<td></td>
<td>-1 meeting with a case manager</td>
<td>Sex: 7M:12F</td>
<td>I: pre19.07 (0.5-35.8), post (6 wks) 15.9±16.7,</td>
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<td></td>
<td>-2 meetings with existing or potential employer</td>
<td>Age (mean, range): I = 32.3 (19-48), C = 30.8 (21-45)</td>
<td>Change: -3.2±14.5</td>
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<td></td>
<td>Manual therapy: Specific mobilisation +/- muscle energy technique on 2-3 cervical spine segments. 15-20 min. Once per week for 2 weeks.</td>
<td>Presentation: persistent</td>
<td>C: pre 27.8 (9.7-68.8), post 29.7±23.1 change:1.9±13.2</td>
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<td>Cold pack: -14°C placed under the neck and shoulders. -15-20 minutes -Once per week for 2 weeks.</td>
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<tr>
<td>Vestibular therapy</td>
<td>Outcome: Seen by physiatrist. Advice to return to normal activities and work Plus Group-based vestibular rehabilitation: -2/week for 8 weeks - Brandt-Daroff, habituation, adaptation/gaze stability, substitution, and balance. -HEP including 2-5 individualised vestibular exercises and general physical activity.</td>
<td>n = I = 33, C = 32</td>
<td>DHI, VSSv, RPQ, BESS</td>
<td>DHI: mean±SD (95% CI) I: pre=47.9±16.6, post= 32.9±21.3</td>
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<tr>
<td></td>
<td>See by physiatrist and multidisciplinary outpatient rehabilitation giving advice to return to normal activities and work.</td>
<td>Sex: 19M:45F</td>
<td></td>
<td>C: pre= 41.4±19.2, post= 36.4±22.7, Mean difference between groups: -8.7 (-16.6, -0.9)</td>
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<tr>
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<td>Seen by physiatrist and multidisciplinary outpatient rehabilitation giving advice to return to normal activities and work.</td>
<td>Age (mean±SD): I = 37.6±12.3, C = 41.2±13.6</td>
<td>VSSv: mean±SD (95% CI) I: pre= 10.9±6.0, post= 6.7±6.0</td>
<td>C: pre= 10.2±6.6, post= 8.4±6.6, Mean difference between groups: -2.1 (-4.5, -0.2)</td>
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<td></td>
<td></td>
<td>Presentation: persistent</td>
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<tr>
<td>Individually tailored multimodal management</td>
<td>Treatment as usual: graded return to sport and school, physiatrist consultation</td>
<td>n = I = 9, C = 10</td>
<td>PCSS, BESS</td>
<td>PCSS: mean±SD</td>
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<tr>
<td></td>
<td>Active rehab: submaximal AE; coordination &amp; sport specific exc.; visualisation of sport; a home exercise program. Cervical manual</td>
<td>Sex: 15M:14F</td>
<td>I: pre= 51.5±27.8, post= 25.0±19.4, change= -24.7±19.1</td>
<td>C: pre= 56.9±31.0, post= 40.3±29.4, change= -15.8±12.5</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Age (mean±SD): 15.5±1.47</td>
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</table>
| Reneker et al.²² | Presentation: persistent therapy vestibular rehab as needed plus 'treatment as usual' (graded return to sport and school, Education, school consultation, physiatrist consultation 6 weeks. | BESS: mean±SD  
I: pre= 16.0±8.1, post= 10.3±3.2  
C: pre= 16.3±15.7, post= 11.4±7.4 | n = I = 22, C = 19  
Sex: 25M:16F  
Age (mean±SD): I = 16.5±2.9, C = 15.9±2.9  
Presentation: persistent  
Progressive treatment: Eight 30-60mins sessions, 2/week. Multimodal tailored interventions depending on symptom presentation:  
- manual therapy (soft tissue release, mobilisations and/or thrust manipulations).  
- vestibular rehabilitation (habilitation, adaptation, gaze stabilisation).  
- oculomotor training (smooth pursuit tracking, convergence, saccades).  
- balance exercises. Dosage and progression determined by treating physical therapist to be maximally therapeutic (i.e. challenging) within symptom-limited parameters. Also received Individualised HEP + exercise education. | Sham, subtherapeutic and non-progressed interventions:  
Eight 30-60mins, 2/week. Received any of the following:  
- Ultrasound.  
- vestibulo-ocular reflex (VOR) cancellation.  
- Laser eye follow.  
- Reading Snellen eye chart.  
- Grade I central/unilateral PA mobilisations.  
- Cx ROM isometric exercises.  
- TENS.  
- predetermined progression plan. Also received standardised HEP: Cx isometric, gentle Cx ROM and VOR cancellation exercises.  
Days to symptom recovery.  
Days to medical clearance for RTS.  
PCSS | Medical clearance for RTS:  
I: 18/22 (82%)  
C: 11/19 (58%)  
Days to symptom recovery: median I: 13.5  
C: 17  
Adjusted HR (95% CI): 1.99 (0.95, 4.15)  
Days to medical clearance for RTS: median I: 15.5  
C: 26  
Adjusted HR (95% CI): 2.91 (1.01, 8.43)  
PCSS: mean±SD  
I: pre = 36.9±13.4, post = 6±8.06  
C: pre = 39.2±13.5, post = 13.7±14.71 | Schneider et al.³⁰  
Sex: 18M:13F  
Age (median, range): I = 15 (12–27), C = 15 (13–30)  
Presentation: persistent | Intervention group: -1/week for 8 weeks or until medical clearance for RTS  
Multimodal tailored interventions depending on symptom presentation: Same as control group plus a combination of:  
- cervical/upper thoracic manual therapy  
- cervical neuromotor retraining  
- sensorimotor retraining  
- vestibular rehabilitation | Control group: - non-provocative ROM exercises  
- stretching  
- postural education  
- rest until symptom free followed by graded exertion | Medical clearance for RTS.  
Pain (0-10)  
ABC  
DHI | Medical clearance for RTS:  
I: 11/15 (73.3%)  
C: 1/14 (7.1%)  
Proportion medically cleared for RTS compared to control (95% CI): 66.2% (40, 92.3)  
Likelihood of medical clearance for RTS compared to control:  
Hazard ratio (95% CI) = 10.27 (1.51, 69.56)  
Likelihood of medical clearance for RTS compared to control with intention-to-treat analysis:  
Hazard ratio (95% CI) = 3.91 (1.34, 11.34)
Abbreviations: ABC (activities-specific balance confidence scale), BCTT (Buffalo Concussion Treadmill Test), BESS (balance error scoring system), C (control), Cx (cervical), DHI (dizziness handicap inventory), F (female), HBI (health behaviour inventory), HEP (home exercise program), HR (heart rate), hr (hour), I (intervention), IQR (interquartile range), M (male), NR (not reported), PCSI (post-concussion symptom inventory), PCSS (post-concussion symptoms scale), ROM (range of motion), RPE (rate of perceived exertion), RPQ3 (physiological subscale in the Rivermead post-concussion symptoms questionnaire), RTS (return to sport), S-Rehab (specialized, interdisciplinary rehabilitation), SD (standard deviation), VSSv (Vertigo Symptom Scale–Short Form, vertigo balance symptoms). Presentation acute ≤ 2 weeks; persistent >2 weeks
<table>
<thead>
<tr>
<th>Study or Subgroup</th>
<th>Control Mean</th>
<th>Control SD</th>
<th>Control Total</th>
<th>Intervention Mean</th>
<th>Intervention SD</th>
<th>Intervention Total</th>
<th>Weight</th>
<th>Std. Mean Difference</th>
<th>IV, Random, 95% CI</th>
<th>Year</th>
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<tbody>
<tr>
<td>Macy 2018</td>
<td>8.14</td>
<td>10.03</td>
<td>7</td>
<td>4.13</td>
<td>5.25</td>
<td>8</td>
<td>12.5%</td>
<td>0.45 [0.58, 1.48]</td>
<td>2018</td>
<td></td>
</tr>
<tr>
<td>Lesby 2019</td>
<td>5.47</td>
<td>16.34</td>
<td>51</td>
<td>1.08</td>
<td>3.91</td>
<td>92</td>
<td>87.5%</td>
<td>0.37 [0.02, 0.76]</td>
<td>2019</td>
<td></td>
</tr>
<tr>
<td>Total (95% CI)</td>
<td>58</td>
<td>60</td>
<td>100.0%</td>
<td></td>
<td></td>
<td>0.38 [0.61, 0.74]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Heterogeneity: Tau^2 = 0.00; CHI^2 = 0.02; df = 1 (P = 0.90); I^2 = 0%.
Test for overall effect: Z = 1.04 (P = 0.30).

Favour Control  | Favour Intervention
<table>
<thead>
<tr>
<th>Study or Subgroup</th>
<th>Control Mean (SD)</th>
<th>Total</th>
<th>Intervention Mean (SD)</th>
<th>Total</th>
<th>Weight</th>
<th>Std. Mean Difference (N, Random, 95% CI)</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Katoishi 2017</td>
<td>15.93 (20.10)</td>
<td>14</td>
<td>4.17 (7.36)</td>
<td>12</td>
<td>17.3%</td>
<td>0.73 (0.07, 1.53)</td>
<td>2017</td>
</tr>
<tr>
<td>Chinman 2019</td>
<td>14.09 (12.22)</td>
<td>11</td>
<td>16.21 (11.58)</td>
<td>19</td>
<td>19.3%</td>
<td>0.31 (0.24, 0.38)</td>
<td>2019</td>
</tr>
<tr>
<td>Rulman 1975</td>
<td>27.6 (8.49)</td>
<td>44</td>
<td>22.29 (14.19)</td>
<td>45</td>
<td>22.8%</td>
<td>0.44 (0.22, 0.66)</td>
<td>1975</td>
</tr>
<tr>
<td>Total (95% CI)</td>
<td>69</td>
<td>78</td>
<td>100.0%</td>
<td>95</td>
<td>96.0%</td>
<td>0.46 (0.13, 0.80)</td>
<td></td>
</tr>
</tbody>
</table>

Heterogeneity: Tau² = 0.00, CH² = 0.59, I² = 2% (P = 0.74); I² = 0%
Test for overall effect Z = 2.73 (P = 0.006)