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REVIEW

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High intensity and sprint interval training, and work-related cognitive function in adults: A systematic review

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Objectives: To assess evidence on the impact of acute and chronic high intensity interval training (HIIT) and sprint interval training (SIT) on work-related performance tests of cognitive function in adults.

Methods: The databases PubMed, CINAHL, Scopus, PsycINFO, Embase, and the Cochrane Library were searched for relevant articles up to August 2022. Eligible studies assessed the effects of HIIT (70%–100% VO_{2max}) and/or SIT (≥100% VO_{2max}) on cognitive function test scores in cognitively healthy adults, relative to a control or comparative exercise group/condition. Data on participant characteristics, exercise protocol, key outcomes, and intervention setting were extracted. Study quality was assessed using a 9 (single session HIIT/SIT) and 14 (multiple session HIIT/SIT) item checklist.

Results: Thirty-six studies (15 countries; n = 11–945 participants) met inclusion criteria. Mean quality scores were "fair-to-good" for acute (single session; mean = 6.9 [SD 1.0]) and chronic (multiple session; mean = 9.8 [SD 1.6]) training studies. Eighteen from 36 studies (12/20 [55%] acute and 6/16 [38%] chronic training studies) evidenced significant improvements in aspects of cognitive function related to work performance (i.e., attention, inhibition, memory, information processing speed, cognitive flexibility, intelligence, reaction time, and learning). Only four studies tested the impact of HIIT/SIT on cognitive function in a work-based setting (e.g., the office or home).

Conclusions: While there is promising evidence, particularly from acute training studies, to indicate that high intensity, short duration exercise benefits cognitive function in adults, there is very limited evidence of application in workplace contexts. To better understand the potential benefits to employee performance and safety, HIIT/SIT and cognitive function research needs to transition from laboratory to "in-situ" occupational settings.

KEYWORDS

acute and chronic impact, cognitive function, high intensity exercise, occupational health and safety, short duration

1 | INTRODUCTION

Workplaces have been identified as a key investment area for population-based physical activity promotion.[1] While there has been a proliferation of studies on workplace physical activity interventions which show a range of positive health, wellbeing, and productivity benefits,[2,3] ongoing research is needed to test new and novel physical activity strategies that can best inform how investment should occur.

High intensity interval training (HIIT) and sprint interval training (SIT) are not new exercise modalities—HIIT for example was first studied in athletes in the 1930s, then in people with cardiac disease in the 1970s[4]—but they are novel in terms of their potential application to occupational health. Both involve one or more short bouts of high intensity exercise, interspersed with periods of low-intensity exercise or rest.[5] However, while HIIT is sub-maximal (e.g., 4 min at 80% maximal heart rate), SIT requires maximal effort (e.g., 30 s of "all-out" exercise).[6] Recent reviews have identified the numerous mechanisms and benefits HIIT/SIT confer to cardiometabolic health in normal and clinical populations.[7,8] In brief, short bursts of high intensity exercise amplify the training stimulus and associated cardiometabolic adaptations. HIIT/SIT are therefore particularly effective at increasing exercise capacity and cardiorespiratory fitness, which is an independant determinant of chronic conditions and risk factors such as coronary heart disease, type 2 diabetes, and hypertension.[4]

The significant health benefits associated with high intensity exercise, in combination with the low time commitment required for exercisers, provide a compelling argument for HIIT/SIT as ideal intervention strategies for sedentary, time-poor workers. HIIT especially has been identified as safe and enjoyable,[9] and able to be performed using different types of exercises (e.g., high knee jogging on the spot, stair stepping, or star jumps) adaptable to a range of work environments and contexts.[10] A recent randomized control trial illustrated the feasibility and efficacy of an 8-week HIIT program with sedentary Australian university workers ($n = 47$).[11] Over 70% of participants in the intervention group completed two or more HIIT sessions/week (30:30 work/rest intervals; 8 min in total); these sessions consisted of aerobic and muscular fitness exercise combinations undertaken at work. Program satisfaction was rated highly, with small-to-medium benefits found for cardiorespiratory fitness and work productivity.

Initial evidence on the viability of short duration, high intensity exercise for occupational health promotion seems promising. However, more research is required to investigate whether HIIT/SIT programs can successfully transition from well-controlled laboratory trials to ecological valid "real-world" settings such as workplaces.[9] In conducting these studies, researchers should not only consider assessing cardiorespiratory fitness and associated health outcomes, but also aspects of cognitive function such as decision-making, attention and learning. These factors are essential for performing work-related tasks successfully, productively, and safely, and are of major concern for employers looking to invest in effective health promotion strategies that can improve business-related outcomes.[12] Physical activity, and particularly aerobic exercise, improves cognitive function, with bi-directional cellular, brain and socioemotional changes put forward as mechanisms that mediate this relationship.[13] Two recent systematic reviews by the same group of researchers concluded that acute HIIT, defined as a single bout of high intensity exercise, has a positive effect on aspects of executive function, a subset of cognitive control processes that directs purposeful behavior[14,15]; some evidence of positive effects on executive function were also found for chronic HIIT, defined as multiple sessions of HIIT that occurred as part of an exercise program over time.[15] However, one of these reviews considered intervention effects for children and adults together,[14] while both reviews included lower level evidence from studies that used a within subjects, pre- to post-test design, excluded SIT studies, and did not extract information on exercise setting. Presently, we are therefore unsure on the extent to which HIIT, SIT, and cognitive function studies have been implemented in work settings, relative to control or comparative group/conditions.

Recognizing these gaps, the aim of the present study was to systematically review evidence on the impact of acute and chronic HIIT and SIT on performance tests of cognitive function in adults. As part of the review and to add to the current knowledge base, we only considered evidence from randomized controlled or cross-over trials. Additionally, we sought to identify how and where studies implemented HIIT/SIT, with the specific purpose of examining the types of HIIT/SIT protocols that have been trialed in workplaces, and their impact on work-related performance tests of cognitive function.

2 | METHODS

The review was conducted using PRISMA guidelines and was registered with the Prospective Register of Systematic Reviews (PROSPERO registration number CRD42018110995). The population of interest was adults (18+ years), who had participated in a HIIT/SIT randomized control/comparative intervention trial, to assess cognitive function outcomes.

2.1 | Literature search

The databases PubMed, CINAHL, Scopus, PsycINFO, Embase, and the Cochrane Library were searched for relevant articles up to August 3, 2022 (see Table S1). The keyword search was performed by two reviewers (DA and ZP) and targeted the exercise modality of interest, in combination with a comprehensive range of cognitive functions. For the exercise modality, we used the terms "interval training" OR "intermittent training" OR "sprint interval training" OR "aerobic interval training" OR "HIIT" OR "high intensity interval training." For cognitive functions, search terms were "cognition" OR "cognitive function" OR "cognitive functioning" OR "executive function" OR "executive functioning" OR "decision-making" OR "selective attention" OR "processing speed" OR alertness OR "reaction time" OR "memory" OR "working memory."

2.2 | Study screening and selection criteria

Screening of titles and abstracts were performed by two reviewers (DA and ZEP), with an additional reviewer (NDG) involved in the screening of full texts. The authors independently applied inclusion and exclusion criteria to study selection, and then met together as a group to agree on those to be included in the review.

To be included, full-text studies needed to be published in English and in peer-reviewed academic journals, and assess the effects of HIIT or SIT on cognitive function in adults relative to a control or comparative group/condition; both acute and chronic training studies were included to allow insights into single and multiple session effects. Studies that assessed multiple intervention components (e.g., HIIT/SIT in combination with nutritional supplements) and/or elite athlete and/or cognitively impaired populations were excluded.

Using definitions provided by Weston et al.,[4] HIIT was defined as interval training with target intensities during at least one interval as follows: 80%–100% PHR/HRmax; 70%–100% VO_2max; 65%–100% HRR/VO_2R; 10.2–11.3 METs; above ventilatory/lactate threshold; 17–18 RPE; and 80%–100% PPO. SIT was defined as all-out, supramaximal intervals (interspersed with recovery periods) with a target intensity ≥100% VO_2max; >11.3 METs; above ventilatory/lactate threshold; ≥18 RPE; >100% of PPO. Studies that did not report physiological intensity parameters but indicated maximal intensity (e.g., cycle as fast as possible) were classified as SIT interventions.

Cognitive function was defined as a range of multiple core and higher level mental abilities that included learning, thinking, reasoning, remembering, problem solving, decision-making, and attention.[12] Based on the neurocognitive framework described by Stillman et al.[13] studies reporting underlying cellular or molecular brain changes, structural and functional brain changes, or behavioral/socioemotional changes were excluded. To therefore be selected in the review, study outcomes needed to report quantitative changes, relative to a control and/or comparative group/condition, in cognitive function measured using a performance-based task.

2.3 | Data extraction and quality assessment

Details on source (authors, year and country), study aim and design, and participant characteristics were extracted from included studies by three reviewers (DA, ZEP, and NDG), who cross-checked data extraction from each paper. Consistent with our study aim, we extracted details on intervention setting (location where HIIT/SIT occurred), protocols (HIIT/SIT training parameters), cognitive function measures (tests and type of cognitive domain assessed), and key outcomes (statistically significant improvements/decreases, or no significant change, in cognitive performance for HIIT/SIT participants, relative to a control or comparative group/condition). We also identified if interventions tested an acute bout of HIIT/SIT at one point in time, or the impact of chronic, multiple HIIT/SIT sessions over a specified number of weeks.

To assess the quality of studies, a checklist was completed for each individual study, based on the exercise-specific TESTEX scale.[16] Each item had a "yes" (1 point), "no," or "unclear" (0 points) response format, resulting in a quality score ranging from 0 to 9 points for acute training studies (poor quality = 0–3 points; fair quality = 4–6 points; and good quality = 7–9 points), and 0–14 for chronic training studies (poor quality = 0–4 points; fair quality = 5–9 points; and good quality = 10–14 points). The five items not assessed for single session training studies were not applicable for interventions testing acute effects of HIIT/SIIT (e.g., exercise attendance over time). Standardized scoring was achieved by three raters (ZR, JJ, NDG) who each independently scored three studies. Inter-reviewer agreement was assessed, and group consensus reached in the case of any disparities in item scores. Following this process, the remaining studies were independently scored by two raters (ZR and JJ), with any conflicts in scoring resolved by the third rater (NDG).

3 | RESULTS

3.1 | Study selection

Following the search and exclusion process (Figure 1), 36 studies[17–52] were included in the review. Excluding duplicates ($n = 4$), and ineligible publication type and populations ($n = 7$), of the 81 full-texts assessed, 24 studies were excluded because of study design (e.g., observational, cross-sectional, or qualitative studies). Ten studies were ineligible because of the intervention used (e.g., included diet), or the publication type (e.g., protocol papers or conference proceedings); 11 studies were ineligible because of the outcome assessed (e.g., assessed underlying cellular or molecular brain changes, or used within group comparisons).

3.2 | Study characteristics

The source and location, aim and research design, and participant characteristics of the included studies are shown in Table 1. Data are presented separately for acute, single session training studies,[17–36] and chronic training programs that delivered multiple sessions.[37–52] The earliest study was published in 2012[18] with only 8% (three studies) published before 2017.[17,18,31] Study locations included 15 countries in Asia/Australasia,[22,24,25,30,31,35,36,40,41,45,49,51] Europe,[18,20,23,27–29,33,34,38,50,52] North America,[19,32,43,44,46–48] South America,[17,26,39,42] Africa,[37] and India.[21] Most studies (20 or 56%) were multiple group (2–4) randomized controlled and/or comparative trials[21,24,25,27,33,37–50,52]; the remaining studies used a single group cross-over trial design.[17–20,22,23,25,30,32,34–36,51] Study participants ($N = 11$[28]–945[52]) were men and women with a mean age ranging from 19[41,46] to 78[52] years. Eight studies assessed participants with specific conditions, or in special populations; these included overweight and/or obese adults,[26,42,45] athletes,[28,36] pre[38] and post[44] menopausal women, and female cancer survivors.[49]

3.3 | Quality assessment

Quality scores and categories (i.e., fair or good) for each of the 36 included studies are shown in the last column of Table 1. The mean percentage agreement on items between raters following independent assessment was 88%, with all differences in scores resolved within the rating pair, without recourse to a third rater. For acute training studies, the mean score was 6.9 (SD = 1.0; range = 5–8) from a possible 9 points, indicating the overall evidence base to be of "fair-to-good" quality. Twelve studies (60%) were classified as "good" (7–9 points),[17,18,20,22–26,28,30,33,34] with eight studies classified as "fair" quality (5 or 6 points).[19,21,27,29,31,32,35,36] The overall evidence base was also of

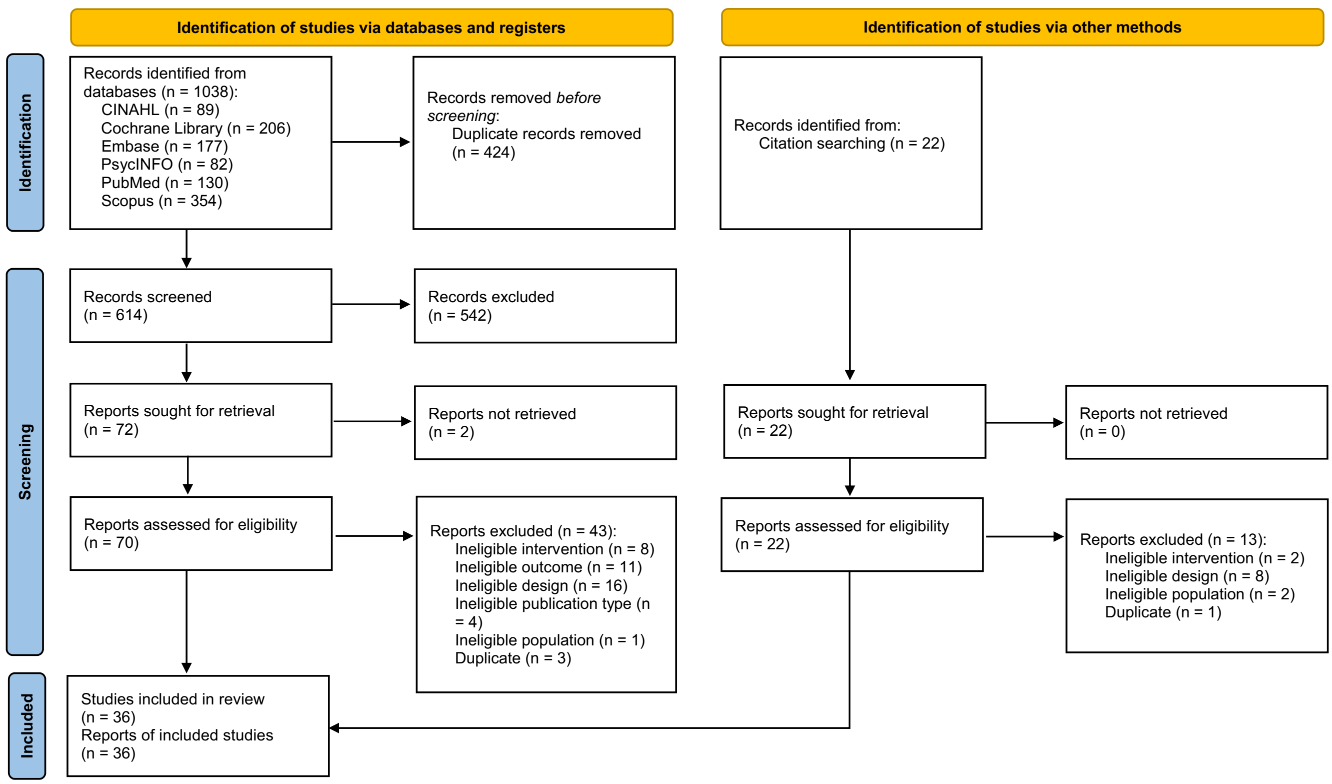

FIGURE 1 PRISMA flow chart.

TABLE 1 Source and location, study aim, participant characteristics, and quality scores of included studies.

Source and Location	Study Aim and Design	Participant Characteristics	Quality Scores
Acute training studies			
Alves et al. (2014)[17]; Brazil	To assess the effects of an acute HIIT session on selective attention and short-term memory. Single group cross-over trial.	22 adults Age: 53.7 + 4.7 years Sex: 59% female BMI: 25.7 + 3.1 kg/m^2	8/9 Good
Budde et al. (2012)[18]; Germany	To assess the effects of HIIT on sustained and selective attention. Single group cross-over trial	46 university students Age: 23.1 + 2.6 years Sex: 43% female BMI: Not reported	7/9 Good
Dupuy et al. (2018)[19]; Canada	To compare the acute effects of HIIT versus MIIT on executive function and heart rate outcomes. Single group cross-over trial	20 moderately trained men Age: 28.0 + 4.8 years Sex: 0% female BMI: Not reported	6/9 Fair
Herold et al. (2022)[20]; Germany	To investigate the effect of SIT on cognitive performance. Single group cross-over trial	19 adults Age: 22.7 + 2.3 years Sex: 58% female BMI: Not reported	8/9 Good
Khandekar et al. (2022)[21]; India	To evaluate the prefrontal cortex hemodynamic response to HIIT during executive function processing. Two group randomized control trial	49 adults Age: 23.9 + 1.5 years Sex: 65% female BMI: 22.8 + 2.2 kg/m^2	6/9 Fair
Kong et al. (2022)[22]; China	To evaluate executive performance responses to sprint interval exercise in normoxia. Single group cross-over trial.	25 active men Age: 22.2 + 2.4 years Sex: 0% female BMI: Not reported	8/9 Good
Ligeza et al. (2018)[23]; Poland	To assess the effects of an acute HIIT versus MICT session on cognitive processes engaged in conflict resolution. Single group cross-over trial	18 men Age: 24.9 + 2.2 years Sex: 0% female BMI: 23.1 + 1.8 kg/m^2	7/9 Good
McSween et al. (2021)[24]; Australia	To investigate the acute effects of different exercise intensities on new word learning. Three group randomized controlled trial.	60 older adults Age: 66.4 + 4.6 years Sex: 72% female BMI: 27.1 + 4.8 kg/m^2	8/9 Good
Nasrollahi et al. (2022)[25]; New Zealand	To determine effects of short bouts of stair climbing on cognitive performance. Singe group cross-over trial.	28 older adults Age: 69.8 + 2.6 years Sex: 50% females BMI: 25.2 + 3.3 kg/m^2	7/9 Good
Quintero et al. (2018)[26]; Colombia	To compare the acute effects of HIIT, RT, and HIIT + RT on executive function. Four group randomized controlled trial.	36 overweight, inactive men Age: 23.6 + 3.4 years Sex: 0% female BMI: 28 + 1.6 kg/m^2	8/9 Good
Schwarck et al. (2019)[27]; Germany	To analyze the acute effects of MICT and HIIT regarding potential inter-individual cognitive differences within the framework of responders and non-responders. Three group randomized controlled cross-over trial.	39 physically active male university students Age: 23.3 + 3.2 years Sex: 0% female BMI: 24.3 + 1.9 kg/m^2	6/9 Fair
Solianik et al. (2021)[28]; Lithuania	To examine the acute effects of sport-specific HIIT on cognition and retinal vessel diameters in experienced amateur boxers. Single group cross-over trial.	11 male amateur boxers Age: 22.8 + 2.9 years Sex: 0% female BMI: Not reported	7/9 Good

(Continues)

TABLE 1 (Continued)

Source and Location	Study Aim and Design	Participant Characteristics	Quality Scores
Sperlich et al. (2018)[29]; Germany	To examine circulatory, metabolic, hormonal, thermoregulatory, cognitive, and perceptual responses while sitting following a brief session of SIT. Single group cross-over trial.	12 university students Age: 22.0 ± 2 years Sex: 58% female BMI: 21.7 ± 2.1 kg/m^2	6/9 Fair
Tsai et al. (2021)[30]; China	To examine the acute effects of HIIT and MICT on executive-related oculomotor performance. Single group cross-over trial.	20 adults Age: 61.15 ± 4.43 years Sex: 100% male BMI: 24.23 ± 2.27 kg/m^2	7/9 Good
Tsukamoto et al. (2016)[31]; Japan	To examine to what extent HIIT impacts post-exercise executive function immediately after exercise and during post-exercise recovery, when compared with MICT. Single group cross-over trial.	12 physically active women Age: 22.9 ± 0.4 years Sex: 0% female BMI: 22.4 + 1.1 kg/m^2	6/9 Fair
Walsh et al. (2019)[32]; USA	To investigate how SIT affects reward positivity amplitude in response to reward feedback. Single group cross-over trial.	25 university students Age: 22.4 ± 3.5 years Sex: 64% female BMI: 22.5 ± 2.4 kg/m^2	5/9 Fair
Wilkie (2020)[33]; Germany	To examine the acute effects of HIIT versus MICT on measures of cognitive performance. Three group randomized controlled trial	35 physically active university students Age: 26.7 ± 3.6 years Sex: 51% female BMI: Not reported	8/9 Good
Wohlwend et al. (2017)[34]; Norway	To investigate the effect of HIIT, MIT, and LIT on cognitive control function. Single group cross-over trial	30 adults Age: 24.3 ± 3.3 years Sex: 50% female BMI: Not reported	7/9 Good
Xie et al. (2020)[35]; China	To examine the acute effects of HIIT on cognitive function in young adults with obesity. Single group cross-over trial	16 obese men Age: 24.5 ± 5.1 years Sex: 0% female BMI: 34.3 ± 4.39 kg/m^2	6/9 Fair
Zhu et al. (2021)[36]; Hong Kong	To investigate the effects of HIIT and MICT across on executive function. Single group cross-over trial.	16 male athletes Age: 21.0 ± 1.7 years; Sex: 0% male BMI: 22.3 ± 1.8 4.39 kg/m^2	6/9 Fair
Chronic training studies			
Coetsee & Terblanche (2017)[37]; South Africa	To assess the impacts of HIIT, MICT, and RT programs on physical and cognitive functioning. Four group randomized controlled trial.	67 inactive, older-aged adults Age: 62.7 + 5.7 years Sex: 69% female BMI: 26.4 + 4.0 kg/m^2	10/14 Good
Connolly et al. (2017)[38]; UK	To compare the effects of self-paced HIIT and CT on health markers and cognitive function. Three group randomized controlled trial.	45 inactive, pre-menopausal women Age: 44.0 + 7 years Sex: 100% female BMI: 26.9 + 6.0 kg/m^2	9/14 Fair
deSousa et al. (2018)[39]; Brazil	To investigate the influence of a SIT program on aerobic capacity and components of attention. Two group randomized controlled trial.	91 university students Age: 23.8 + 4.8 years Sex: 48% female BMI: 24.4 + 3.9 kg/m^2	9/14 Fair
Eather et al. (2019)[40]; Australia	To evaluate the efficacy and feasibility of a HIIT program on fitness and executive function. Two group randomized wait-list controlled trial.	53 university students Age: 20.4 + 1.9 years Sex: 66% female BMI: 23.6 + 4.1 kg/m^2	7/14 Fair

TABLE 1 (Continued)

Source and Location	Study Aim and Design	Participant Characteristics	Quality Scores
Hu et al. (2021)[41]; China	To assess the effect of short-term HIIT on executive function and neuroplasticity. Two group randomized controlled trial.	32 sedentary women Age: 19.2+0.6 years Sex: 100% female BMI: 21.2+0.7 kg/m^2	9/14 Fair
Inoue et al. (2020)[42]; Brazil	To compare the effects of a HIIT versus MICT training program on abdominal fat, brain derived neurotrophic factor and executive function. Two group randomized comparative trial.	20 obese, sedentary men Age: 30.0+5.4 years Sex: 0% female BMI: 34.4+3.5 kg/m^2	9/14 Fair
Kovacevic et al. (2020)[43]; Canada	To compare the effects of a HIIT versus MICT training program on cognitive function and in sedentary older adults. Three group randomized controlled trial.	64 sedentary older adults Age: 72.0+5.7 years Sex: 61% female BMI: 28.3+4.6 kg/m^2	11/14 Good
Lee et al. (2019)[44]; Canada	To investigate the effects of HIIT versus MICT on aerobic exercise capacity. Two group randomized comparative trial.	31 post-menopausal women with coronary artery disease Age: 69.6+7.9 years Sex: 100% female BMI: 27.3 + 4.9 kg/m^2	12/14 Good
Li et al. (2021)[45]; China	To compare the effects of 12 weeks of HIIT versus VICT on cognitive function, physical and cardiorespiratory fitness and BDNF in elderly adults. Three group randomized controlled trial.	57 physically inactive, overweight, or obese elderly adults Age: 65.1+4.0 years Sex: 46% female BMI: 27.5+1.8 kg/m^2	9/14 Fair
May et al. (2018)[46]; USA	To examine the effectiveness of a self-regulatory biofeedback intervention program in contrast to HIIT and inactive control for reducing school burnout. Three group randomized wait-list controlled trial.	90 university students Age: 18.6+1.0 years Sex: 82% female BMI: Not reported	11/14 Good
Mekari et al. (2020a)[47]; Canada	To compare the effects of SIT and MICT on cognitive functioning. Two group randomized comparative trial.	25 adults Age: 32.0+8 years Sex: 72% female BMI: 27+6 kg/m^2	11/14 Good
Mekari et al. (2020b)[48]; Canada	To compare the effects of HIIT, MICT, and RT on cognitive functioning and cardiorespiratory fitness. Three group randomized comparative trial.	69 older adults Age: 68.0+7 years Sex: 67% female BMI: 26+5 kg/m^2	10/14 Good
Northey et al. (2019)[49]; Australia	To investigate the effects of HIIT and MICT on cognitive function. Three group randomized wait-list controlled trial.	17 female cancer survivors Age: 62.9±7.8 years Sex: 100% female BMI: 26.9+5.9 kg/m^2	12/14 Good
Sokolowski et al. (2021)[50]; Norway	To examine the effects of supervised aerobic exercise training at different intensities on cognition. Three group randomized controlled trial.	87 older adults Age: 72.4±1.9 years Sex: 52% male, 48% female BMI: 26.0±3.37 kg/m^2	8/14 Fair
Zhang et al. (2021)[51]; China	To assess the effectiveness of an online HIIT intervention on cognitive. Single group randomized controlled trial.	62 female adults Age: 22.72±2.22 years Sex:100% female BMI: 21.88±7.03 kg/m^2	12/14 Good
Zotcheva et al. (2022)[52]; Norway	To examine the effects of supervised aerobic exercise training at different intensities on cognition. Three group randomized controlled trial.	945 older adults Age: 78.2±2.02 years Sex: 52% male, 48% female BMI: Not reported.	8/14 Fair

Abbreviations: BMI, body mass index; CT, continuous training; HIIT, high-intensity interval training; LIT, low-intensity training; MICT, moderate intensity continuous training; MIIT, moderate intensity interval training; MIT, moderate intensity training; RT, resistance training; SIT, sprint interval training; VICT, vigorous intensity continuous training.

"fair-to-good quality" for chronic training studies (mean score = 9.8; SD = 1.6; range = 7–12 from a possible 14 points). Eight of these studies (50%) were classified as "good" (10–14 points),[37,43,44,46–49,51] with eight studies (50%) classified as "fair" quality (7–9 points).[38–42,45,50,52]

An overview of the number and proportion of studies scoring a point for each of the TESTEX criteria is shown in Table 2. All 36 studies scored on Items 1 (eligibility criteria stated), 10 (between group/treatment statistical comparisons), and 14 (exercise parameters). More than half the studies scored on all the remaining items, apart from Items 2 (randomization—acute training studies), 3 (allocation concealment—acute training studies), 5 (blinding of assessors—acute and chronic training studies), 9 (intention to treat—chronic training studies), and 12 (activity monitoring in control group—chronic training studies).

3.4 | Intervention protocols

The study settings, intervention protocols, cognitive function measures, and key outcomes are summarized in Table 3. HIIT/SIT sessions or programs were mostly supervised in-person and performed in a laboratory exercise facilty[17–27,30,31,36,41,43,47,49,50,52]; four (11%) studies required participants to perform HIIT/SIT outside this setting, either at a private gym,[28] an office,[29] unsupervised at home,[44] or online via telehealth.[51] Studies compared HIIT or SIT in these settings to rest,[18,20–23,25,28,29,29,30,32,34,35] or a "no exercise" condition or group.[26,27,37–41,46,49,51] Other exercise modalities included low[17,24,33] and/or moderate[19,23,24,27,30,31,33,34,36,37,42–45,47–50,52] intensity conditions or groups, and/or resistance training.[26,37,44,48]

Twelve acute training studies used cycle ergometer or treadmill HIIT protocols,[17–19,21,23,24,27,30,31,33,35,36]

TABLE 2 TESTEX scale items and the number (%) of studies scoring a point for each item.

Item	Description	*n* (%) A	*n* (%) B
1	**Eligibility criteria**—specified and fulfilled, and diagnostic test values should be provided.	20 (100%)	16 (100%)
2	**Randomization specified**—a description of the method used to allocate participants to groups or conditions should be provided.	9 (45%)	8 (50%)
3	**Allocation concealment**—it should be stated whether participants were unaware, when the decision was made, of the group or condition order allocated.	9 (45%)	8 (50%)
4	**Baseline characteristics**—Data of all participants who were randomized should be presented. For multiple group studies, there should be no significant differences between groups in the main baseline measure.	19 (95%)	16 (100%)
5	**Blinding of assessor**—it should be stated whether assessors of the main outcome measure were blinded.	1 (5%)	1 (6%)
6	**Main outcome measure assessed in at least 85% of participants**—the percentage of participants completing the study should be reported.	19 (95%)	11 (69%)
7	**Reasons for dropout**—where required, the percentage loss of participants, and reasons why dropout occurred should be reported.	NA	8 (50%)
8	**Exercise attendance**—the percentage of exercise sessions completed by participants who did not withdraw should be reported.	NA	13 (81%)
9	**Intention-to-treat**—where required, this analysis should be added to those who did complete the study.	NA	6 (38%)
10	**Within/between group analyses**—comparisons for the main outcome measure should be reported.	20 (100%)	16 (100%)
11	**Measures of variability**—at least standard deviations should be reported for the main outcome measure.	19 (95%)	16 (100%)
12	**Activity monitoring in control group**—some measure (i.e., activity diary) should be supplied so cross-over effect of the control group can be quantified.	NA	7 (44%)
13	**Relative exercise intensity remained constant**—periodic assessment of exercise capacity should be conducted and the intensity titrated up so exercise intensity remains constant.	NA	15 (94%)
14	**Exercise parameters**—session and program duration, session frequency, exercise training intensity, and modality should be clearly reported.	20 (100%)	16 (100%)

Note: A: Acute training studies ($n = 20$); B: Chronic training studies ($n = 16$).

TABLE 3 Intervention protocols, cognitive function measures, and key outcomes.

Source	Intervention protocols	Cognitive function measures	Key outcomes
Acute training studies			
Alves et al. (2014)[17]	Setting: Laboratory/exercise facility (supervised). HIIT (cycle ergometer): 20 min (10× 1-min intervals [80% heart rate reserve], interspersed with 1-min active recovery periods [60% heart rate reserve]). Control: Low-intensity active stretching (15 min).	Selective attention (Stroop Test) and short-term memory (Digit Span Test). Measured pre- and post-session (time not specified).	HIIT significantly improved selective attention compared to low-intensity active stretching. No significant effects observed for short-term memory.
Budde et al. (2012)[18]	Setting: Laboratory/exercise facility (supervised). SIT (running): 8 min (2× 3-min all-out sprint intervals [100% HRmax], interspersed with 2-min passive recovery). Control: Seated rest (8 min).	Sustained/selective attention (d2-Test). Measured pre- and post-session (time not specified).	SIT significantly improved sustained and selective attention compared to seated rest. Improvements observed for high but not low-active participants.
Dupuy et al. (2018)[19]	Setting: Laboratory/exercise facility (supervised). HIIT (cycle ergometer): 36 min (6 × 3-min intervals [95% peak power output], interspersed with 3-min passive recovery). MICT (cycle ergometer): 36 min (6 × 3-min intervals [60% peak power output], interspersed with 3-min passive recovery).	Cognitive flexibility (Stroop Test) Measured pre-, during and post-session (+15, 30, 45, and 60 min).	No significant differences observed.
Herold et al. (2022)[20]	Setting: Laboratory/exercise setting (supervised). SIT (cycle ergometer); 3-min warm up followed by 6× 6-second max all out intervals interspersed with 1-min passive rest periods. Control: Seated rest (20 min).	Attention (d2 test). Working memory (Digit Span Backward/Forward). Measured pre- and post-session (10 min).	SIT significantly improved attention compared to seated rest. No significant effects observed for working memory.
Khandekar et al. (2022)[21]	Setting: Laboratory/exercise setting (supervised). HIIT (cycle ergometer); 4× 4 min intervals at 90%–95% HRmax interspersed with 3 min of active recovery. Control: Seated rest (duration of HIIT).	Reaction time (Stroop Test). Processing speed (Trail Making Test). Measured pre- and post-session (15 min).	HIIT significantly improved reaction time and processing speed compared to the control.
Kong et al. (2022)[22]	Setting: Laboratory/exercise setting (supervised). SIT (cycle ergometer); 20× 6 s of max all intervals interspersed with 15-s passive recovery. Control: Seated rest (7 min)	Reaction time (Stroop Test) Measured pre- and post-intervention (10, 30, and 60 min)	SIT significantly improved reaction time compared to seat rest.
Ligeza et al. (2018)[23]	Setting: Laboratory/exercise setting (supervised). HIIT (cycle ergometer); 24 min (4× 3-min intervals [intensity individually determined using ventilatory thresholds], interspersed with 3-min active recovery periods). MICT (cycle ergometer); 24 continuous min (intensity individually determined using ventilatory thresholds). Control: Seated rest (24 min).	Inhibition (Flanker Task). Measured pre- and post-session (time not specified).	No significant difference between HIIT and rest. MICT significantly improved inhibition compared to HIIT.

(Continues)

TABLE 3 (Continued)

Source	Intervention protocols	Cognitive function measures	Key outcomes
McSween et al. (2021)[24]	Setting: Laboratory/exercise facility (supervised). HIIT (cycle ergometer): 5 min warm up at 50%–60% of HRmax, 4×4 min high-intensity cycle intervals at 85%–95% of HRmax interspersed with 3×3 min passive rest at 50%–65% of HRmax. MICT (cycle ergometer): 5 min warm up at 50%–60% of HRmax, a 30 min cycling bout at 55%–75% of HRmax. Control: Stretching (38 min) with 1 min break at midpoint.	Word learning (associative novel word learning task). Measured 10 min and 1 week post-session.	No significant difference between HIIT and MICT/ control.
Nasrollahi et al. (2022)[25]	Setting: Laboratory/exercise facility (supervised). HIIT (stair-climbing): 6 ×1 min intervals climbing up interspersed with 1 min recovery. Control: Seated rest (25 min).	Reaction time (Pro/Anti test) Measured 5-min rest post-session.	HIIT significantly improved reaction time in comparison with seated rest.
Quintero et al. (2018)[26]	Setting: Laboratory/exercise facility (supervised). HIIT (type of exercise not specified): 32 min (4×4 min intervals [85%–95% HRmax], interspersed with 4-min active recovery periods [75%–85% HRmax]). RT: 12–15 repetitions per set of 6 exercises (all major muscle groups; 50%–70% of 1RM; interspersed with 60-s recovery). HIIT + RT: 50% each condition; (time not specified). Control: No exercise (time not specified).	Inhibition (Stroop Test), and attentional capacity (d-2 Test). Measured pre- and post-session (time not specified).	HIIT significantly improved inhibition and attentional capacity compared to control. No significant differences for other exercise conditions.
Schwarck et al. (2019)[27]	Setting: Laboratory/exercise facility (supervised). HIIT (treadmill): 25 min (5×2-min intervals [90% VO_{2max}], interspersed with 3-min active recovery [40% VO_{2max}]). MICT (treadmill): 30 min (40–59% VO_{2max}). Control: Sedentary (10 min).	Selective attention (d-2 Test), inhibition (Stroop Test), and information processing speed (Trail Making Test). Measured pre- and post-session (time not specified).	No significant differences between HIIT, MICT and the control.
Solianik et al. (2020)[28]	Setting: Exercise facility (supervised). HIIT: 12 min session (3 sets of 3-min boxing rounds, interspersed with 1-min break). Control: Seated rest (21 min)	Motor speed (Simple Reaction Time Test) Cognitive flexibility (Procedural Reaction Time Test) Working memory (Mathematical Processing Test) Inhibition (Go/ No-Go Test) Measured pre- and post- session (time not specified).	HIIT significantly improved cognitive flexibility and inhibition compared to rest.
Sperlich et al. (2018)[29]	Setting: Office (supervised) SIT (circuit): 6 min (8× exercises; 10–20 s intervals at maximal intensity). Control: Seated rest (180 min).	Information processing speed, selective attention and inhibition (Stroop Test). Measured pre- and post-session (immediately +30, 60, 90 and 120 min).	No significant difference between SIT and the rest condition.

TABLE 3 (Continued)

Source	Intervention protocols	Cognitive function measures	Key outcomes
Tsai et al. (2021)[30]	Setting: Laboratory/exercise facility (supervised). HIIT (cycle ergometer): 4 min warm-up, 24 min intervals (1 min, 70%–75% Heart Rate Reserve) alternated with an active recovery period (2 min, target RPE = 9–11), 2 min cool-down. MICT: 4 min warm-up, 24 min of exercise (50%–55% Heart Rate Reserve), 2 min cool-down. Control: Seated rest (35 min).	Reaction time (Saccadic Paradigm). Measured pre- and post-session (time not specified).	No significant difference between HIIT, MICT and control.
Tsukamoto et al. (2016)[31]	Setting: Laboratory/exercise facility (supervised). HIIT (cycle ergometer): 33 min (5 min [60% VO_{2peak}], followed by 4 × 4-min intervals [90% VO_{2peak}], interspersed with 3-min active recovery periods [60% VO_{2peak}]). MICT (cycle ergometer): 40 min (60% VO_{2peak}).	Selective attention and inhibition (Stroop Test). Measured pre- and post-session (immediately +10, 20 and 30 min).	HIIT significantly improved selective attention and inhibition compared to MICT 30+ min post-exercise.
Walsh et al. (2019)[32]	Setting: Laboratory/exercise facility (supervised). SIT (circuit): ~11 min (4× 20-s all-out intervals, interspersed by 10-s passive recovery, and 1-min rest periods). Control: Seated rest.	Reward learning (Novel Gambling Task). Measured pre- and post-post-session (10 min).	No significant difference between SIT and the rest condition.
Wilkie (2020)[33]	Setting: Laboratory/exercise facility (supervised) SIT: 15 whole-body exercises for 15 min (20 s all-out training bouts, with 10-s rest periods). MICT (treadmill): Walking for 15 min (60% HRR). Control: Seated rest (15 min).	Information processing speed (Stroop test, Trail Making Test) Inhibition (Stroop Test) Cognitive flexibility (Trail Making test) Working memory (Digit Span test) Short-term memory (Digit Span test) Measured pre- and post –session (+30 s).	SIT significantly improved short-term and working memory compared to MICT and rest.
Wohlwend et al. (2017)[34]	Setting: Laboratory/exercise facility (supervised). HIIT (treadmill): 28 min (4 × 4 min intervals [85% VO_{2max}], interspersed with 3-min active recovery periods [40% VO_{2max}]). MICT: (treadmill): Running times were calculated so that exercise resulted in equal oxygen consumption as HIIT (60% VO_{2max}). Low-intensity training (treadmill): Running times were calculated so that exercise resulted in equal oxygen consumption as HIIT (40% VO_{2max}).	Cognitive control function (Conner's Continuous Performance Test). Measured pre- and post-session (time not specified).	HIIT significantly improved cognitive control compared to MICT and low-intensity training. Improvements were transient, returning to baseline after 20 min while performing the cognitive control function test.
Xie et al. (2020)[35]	Setting: Laboratory/exercise facility (supervised) HIIT (cycle ergometer): 20-min session (10× 1-min intervals [80%–90% HRmax], interspersed with 1-min active recovery periods [50%–65% HRmax]). Control: Seated rest (30 min)	Information processing speed (Flanker Task) Inhibition (Flanker Task) Measured pre- and post-session (+15 min).	HIIT significantly improved information processing speed and inhibition compared to rest.

(Continues)

TABLE 3 (Continued)

Source	Intervention protocols	Cognitive function measures	Key outcomes
Zhu et al. (2021)[36]	Setting: Laboratory/exercise facility (supervised). HIIT (running and cycling): 5 min (60% of VO_{2max}) followed by 4 × 4-min bouts (90% of VO_{2max}) with 3 min of active recovery. MICT: 40 min of running and cycling at 60% VO_{2max}	Reaction time (Eriksen Flanker Test). Measured pre and post (0 and 10 min)	No significant differences between HIIT and MICT.
Chronic training studies			
Coetsee & Terblanche (2017).[37]	Setting: Laboratory/exercise facility (supervised). HIIT (treadmill): 16 weeks × 3 sessions/week; 28 min/session (4 × 4-min intervals [90%–95% HRmax], interspersed with 3-min active recovery periods [70% HRmax]). MICT (treadmill): 16 weeks × 3 sessions/week; 47 min/session (70%–75% HRmax). RT (fixed and free weights): 16 weeks × 3 sessions/week; upper and lower body exercises; 3 sets × 10 reps (10%, 75%, and 100% of 1RM). After 8 weeks, set load increased to 75%, 85%, and 100% of the 1RM. Control: No exercise.	Information processing speed (Stroop Test). Measured pre- and post-program.	No significant differences between HIIT and MICT/RT.
Connolly et al. (2017)[38]	Setting: Laboratory/exercise facility (supervised). HIIT (cycle ergometer): 12 weeks × 3 sessions/week; 35 min sessions (5× 5-min repetitions; 30-s low [30% max effort], 20-s moderate [50–60% max effort] and 10-s high (>90% max effort) intensity cycling, interspersed with 2-min passive recovery). Continuous training (cycle ergometer): 12 weeks × 3 sessions/week; 50 min/session of continuous cycling at a self-paced intensity. Control: No exercise.	Visual learning and memory (One Card Learning Task). Working memory (1/2 Back Task). Verbal learning and memory (International Shopping List Task). Measured pre- and post-program.	HIIT and continuous training significantly improved visual/verbal learning and memory compared to the control group. No significant differences between HIIT and continuous training.
deSousa et al. (2018)[39]	Setting: Laboratory/exercise facility (supervised). SIT (cycle ergometer): 2 weeks × 3 sessions/week; 12–24 min sessions (4 × 30 s "all-out" efforts [>90% HRmax], interspersed with active recovery periods [3–4 min]). Control: No exercise.	Attention (Attention Network Test) Measured pre- and post-program.	No significant differences between SIT and control.
Eather et al. (2019)[40]	Setting: Laboratory/exercise facility (supervised). HIIT (circuit): 8 weeks × 3 sessions/week; 8–12 min sessions with work-to-rest ratio of 30 s (target intensity during work periods >85% HRmax). Control: No exercise.	Cognitive flexibility (Trail Making Test). Measured pre- and post-program.	HIIT significantly improved cognitive flexibility compared to the control group.

TABLE 3 (Continued)

Source	Intervention protocols	Cognitive function measures	Key outcomes
Hu et al. (2021)[41]	Setting: Laboratory/exercise facility (supervised) HIIT (cycle ergometer): 2 weeks × 4 sessions/ week; 21 min sessions (4 × 2-min intervals [90% heart rate reserve], interspersed with 4-min active recovery [50% heart rate reserve]). Control: No exercise.	Cognitive flexibility (Stroop Test) Measured pre- and post- program.	No significant differences between HIIT and control.
Inoue et al. (2020)[42]	Setting: Not reported (supervised). HIIT (treadmill): 6 weeks × 3 sessions/ week. 20 min session (10 × 1-min intervals [100% maximal aerobic velocity], interspersed with 1-min passive recovery). MICT (treadmill): 6 weeks × 3 sessions/ week. Walking/running [65% maximal aerobic velocity].	Information processing speed (Stroop Test) Inhibition (Stroop test) Intelligence (BETA-III test). Measured pre- and post-program.	No significant differences between HIIT and MICT.
Kovacevic et al. (2020)[43]	Setting: Not specified (supervised). HIIT (treadmill):12 weeks × 3 sessions/ week. 28 minute sessions (4 × 4-min intervals [90%–95% peak heart rate], interspersed with 3-min active recovery [50%–70% peak heart rate]). MICT (treadmill): 12 weeks × 3 sessions/week. 47 minute sessions (walking [70%–75% peak heart rate]). Control: 12 weeks × 3 sessions/week. 30 minute sessions of stretching.	High interference memory (Mnemonic Similarity Task) Inhibition (Go/No-Go Test and Flanker Task). Measured pre- and post-program.	HIIT significantly improved high-interference memory compared to MICT and a stretching control. No significant differences for inhibition.
Lee et al. (2019)[44]	Setting: Exercise facility/home (unsupervised) HIIT (treadmill): 24 weeks × 5 sessions/week; Week 1–6 (30–40 min of walking/jogging [60%–80% VO_{2peak}]); Week 7–24 (28 min of 4 × 4-min intervals [90%–95% HRmax], interspersed with 3-min active recovery periods [50%–70% HRmax]). MICT (treadmill): 24 weeks × 5 sessions/week (30–40 min of walking/jogging [60%–80% VO_{2peak}]).	Information processing speed (Trail Making Test). Attention (Digit Symbol Encoding Task). Psychomotor processing speed (Wechsler Adult Intelligence Scale). Verbal memory (California Verbal Learning Test). Measured pre- and post-program.	No significant differences between HIIT and MICT.
Li et al. (2021)[45]	Setting: Not specified (supervised). HIIT (recumbent lower body ergometer): 12 weeks × 3 sessions/week. 25 min sessions (4 × 3-min intervals [90% VO_2max], interspersed with 3-min active recovery periods [60% VO_2max]). MICT (recumbent lower body ergometer): 12 weeks × 3 sessions/week. 25 min sessions [70% of VO_2max]. Control: Normal lifestyle.	General cognitive function (Montreal Cognitive Assessment; Binet-Simon Intelligence Scale) Measured pre- and post-program.	No significant differences Between HIIT and MICT/ control.
May et al. (2018)[46]	Setting: Laboratory/exercise facility (supervised). HIIT (cycle ergometer): 4 weeks × 3 sessions/ week; 20 min sessions (10 × 1-min intervals [90% HRmax], interspersed with 1-min recovery [passive or active at 50 W]). Heart rate variability training: (stress reduction strategies and biofeedback): 4 weeks × 3 sessions/week. Control: No exercise or biofeedback.	Working memory (Serial Subtraction Task). Measured pre- and post-program.	No significant differences between HIIT and control. Heart rate variability training significant improved cognitive function compared to HIIT and a control.

(Continues)

TABLE 3 (Continued)

Source	Intervention protocols	Cognitive function measures	Key outcomes
Mekari et al. (2020)[47]	Setting: Laboratory/exercise facility (supervised). SIT (cycle ergometer): 6 weeks × 3 sessions/week; 40–45 min sessions (15 s intervals [100% peak power output], interspersed with 15 s of passive recovery), in 2× 20 min blocks. MICT (cycle ergometer): 6 weeks × 3 sessions/week; 34–39 min sessions (60% Peak Power Output).	Inhibition (Stroop Test). Cognitive flexibility (Trail Making Test). Measured pre- and post-program.	SIT significantly improved cognitive flexibility compared to MICT.
Mekari et al. (2020b)[48]	Setting: Not specified (supervised). SIT (cycle ergometer): 6 weeks × 3 sessions/week; 40–45 min sessions (15 s intervals [100% peak power output], interspersed with 15 s of passive recovery), in 2× 20 min blocks. MICT (cycle ergometer): 6 weeks × 3 sessions/week. 34–39 min sessions (60% peak power output). RT: 6 weeks × 3 sessions/week. 8–10 exercises using major muscle groups, 8–12 reps per exercise.	Information processing speed (Stroop Test) Inhibition (Stroop Test) Cognitive flexibility (Stroop Task) Measured pre- and post-program.	SIT significantly improved cognitive flexibility compared to MICT and RT. No significant differences for information processing speed or inhibition.
Northey et al. (2019)[49]	Setting: Laboratory/exercise facility (supervised). HIIT (cycle ergometer): 12 weeks × 3 sessions/week; Week 1 (10-min session of 4 × 30-s intervals [> 90% HRmax], interspersed with 2-min active recovery periods). Week 2–12 (intervals increased each week until the target of 7 intervals achieved). MICT (cycle ergometer): 12 weeks × 3 sessions/week; 20 min sessions (55%–65% peak power). Control: No exercise.	Verbal learning and delayed recall (International Shopping List). Working memory (One-Back Test). Measured pre- and post-program.	No significant differences between HIIT and MICT/control.
Sokolowski et al. (2021)[50]	Setting: Not specified (supervised) HIIT: 10-min warm-up with subsequent 4 × 4-min intervals at 85%–95% of peak heart rate, (16–20 Borg scale), twice weekly for 5 years. MICT: 50 min of continuous training at 70% of peak heart rate, twice weekly for 5 years. HIIT and MICT attended mandatory spinning class every 6th week, where participants exercised with a heart rate monitor to ascertain compliance with the prescribed training intensity. Control: Followed national physical activity recommendations of 30 min of MVPA/day/5 years.	Spatial/verbal/working memory (Objects in Grid Test; The California Verbal Learning Test; Digit Span Backwards Test). Processing speed (Number Comparison and the Letter Comparison Test). Planning ability (modified Tower of London Test). Measured at 0, 1, 3, and 5 years.	No significant differences between HIIT and MICT/control.

TABLE 3 (Continued)

Source	Intervention protocols	Cognitive function measures	Key outcomes
Zhang et al. (2021)[51]	Setting: Home-based telehealth. HIIT (Circuits): 6 weeks × 2 HIIT group sessions of 60 min (5 min warm-up; 35 min of HIIT [30 s exercise repetitions with 30 s passive recovery split into 2× 15 min circuits of bodyweight, core and endurance exercises above 80% of peak HR]); 10 min stretching and relaxation; 10 min education. Control: Education only (6 weeks).	Global cognitive function: Processing speed, working memory, episodic memory, visual–spatial ability, and a verbal ability test (computer administered test). Measured 0, 3, and 6 weeks.	HIIT significantly improved global cognitive function compared to the education only control.
Zotcheva et al. (2022)[52]	Setting: Not specified (supervised) HIIT: 10-min warm-up with subsequent 4 × 4-min intervals at 85%–95% of peak heart rate, (16–20 Borg scale), twice weekly for 5 years. MICT: 50 min of continuous training at 70% of peak heart rate, twice weekly for 5 years. HIIT and MICT attended mandatory spinning class every 6th week, where participants exercised with a heart rate monitor to ascertain compliance with the prescribed training intensity. Control: Followed national physical activity recommendations of 30 min of MVPA/day/5 years.	Global cognition function (Montreal Cognitive Assessment scale). Measured at 0, 1, 3, and 5 years.	No significant differences between HIIT and MICT/control.

Note: Significance reported at $p < 0.05$.

Abbreviations: HIIT, high-intensity interval training; MICT, moderate intensity continuous training; RT, resistance training; SIT, sprint interval training.

with the frequency and duration of HIIT ranging from 10× 1-min[17] to 6× 3-min bouts,[19] with 1–4 min of active recovery; one of these studies used 3× 3-min boxing rounds, interspersed with 1 min breaks,[28] while another used 6× 1 min intervals of stair climbing with 1 min of recovery.[25] Six acute training studies utilized "all-out effort" SIT protocols, consisting of 20-m sprints,[18] stationary cycling[20,22] or 4-to-15 circuit exercises lasting 20 s each.[29,32,34] Nine chronic training studies used cycle erogometer or treadmill HIIT protocols,[37,38,41–46,49] and two studies a HIIT circuit.[40,51] Program duration ranged from 2 to 24 weeks, with 3–5 sessions/week. HIIT frequency and duration ranged from 7× 30-s bouts,[49] to 5×5 min-bouts[38] with 1–4 min of active recovery. Three studies in this category used SIT cycle ergometer protocols consisting of 4× 30-s bouts, with 3–4 min active recovery,[39] and 15 s of "all-out effort" with 15 s of passive recovery, in 2× 20 min blocks.[47,48] These studies ran for 2 and 6 weeks, respectively, with 3 sessions/week. Two studies used different data sets from the same longitudinal project, which ran 4× 4 min HIIT protocols over 5 years; neither of these studies specified HIIT modalities beyond intensity titration every 6 weeks using a spinning class.[50,52]

3.5 | Measures and outcomes

Twenty-nine different performance measures of cognitive function were used in the 36 selected studies. The most popular measures were "The Stroop Test" ($n = 14$ [39%] studies),[17,19,21,22,26,27,29,31,34,37,41,42,47,48] "The Trail Making Test" ($n = 6$ [17%] studies),[27,34,40,43,47] and the "d2"[18,20,26,27] and "Flanker"[23,35,36,44] tests (four studies [11%] each).

Twelve (from 20 [60%]) acute training studies evidenced significant improvements in cognitive function for participants doing HIIT[17,21,25,26,28,31,34,35] or SIT.[18,20,22,33] Four acute training studies indicated cognitive performance was better for HIIT than for low-intensity stretching[17,33] and/or MICT,[31,33,34] with nine studies showing improved performance for HIIT[18,21,25,26,28,34,35] or SIT[20,22] relative to rest. Six (from 16 [38%]) chronic training studies indicated significant improvements for HIIT compared with a "no exercise" group,[38,40,51] or MICT/low-intensity stretching,[43] and for SIT participants relative to MICT,[47,48] and resistance training.[48] Relative to quality assessment and the level of evidence (i.e., poor, medium or good), 66% (13/18 studies) of the HIIT/SIT acute and chronic training interventions that found positive intervention effects were of good quality.[17,18,20,22,25,26,28,33,34,43,47,48,51]

Outcome data were collapsed when assessed at least twice, and considered in the six cognitive domains of attention, inhibition, memory, information processing speed, cognitive flexibility, and reaction time; an additional "other" category included cognitive functions only assessed once (e.g., motor speed, reward learning, and intelligence), and studies that did not specify the cognitive domain being examined (Figure 2). Out of nine studies that tested attention, five (56%; all acute training) showed improved performance due to HIIT[17,26,31] or SIT.[18,20] Inhibition improved with HIIT in 4/12 studies (33%; all acute training)[26,28,31,35]; memory improved in 3/10 studies (30%; one acute and two chronic training studies) with SIT[34] and HIIT.[38,44] Information processing speed improved with HIIT in 2/10 studies (20%; acute training)[21,35]; and 4/7 studies (57%; one acute and three chronic training studies) found improvements in cognitive flexibility with HIIT[28,40] and SIT.[47,48] Reaction time decreased and improved in 3/5 studies (60%; acute training).[21,22,25]

4 | DISCUSSION

This study systematically reviewed evidence on the impact of HIIT and SIT on performance-based tests of cognitive function in adults. A key aim of the review was to examine the types of HIIT/SIT protocols that have been tested in workplaces. Half of the studies included in the review (18/36) found significant improvements in cognitive function. Studies were of fair-to-good quality and assessed 66 intervention effects across a broad range of cognitive function domains that included attention, inhibition, memory, information processing speed, reaction time, cognitive flexibility, intelligence, and learning. Around a third of these intervention effects were positive (24/66 or 36%), with improvements relative to a control and/or exercise/rest condition more pronounced in acute single session training studies (17/37; 46%), as opposed to those studies that tested the chronic impact of HIIT/SIIT and multiple session training programs (7/29; 24%). Only four studies (11% of those included in the review) examined the impact of HIIT/SIT on cognitive function outside of the laboratory, and in contexts that might be applied to workplace settings (i.e., a private gym, the office, home, or via online delivery); two of these studies found significant intervention effects for HIIT.

Based on these findings, we posit that the evidence base shows promise in support of the benefits of high intensity, short duration exercise for cognitive function in adults. In comparison with other reviews, Hsieh et al.[15] found a higher number of positive intervention effects for HIIT in fewer domains (i.e., inhibition, memory, and cognitive flexibility), through both acute and chronic training (56%, or 14/25 intervention effects assessed in 23 selected studies). A possible reason for this is that we targeted a broader set of cognitive function domains, rather than those just associated with executive function. Unlike previous reviews, we also included HIIT and SIT studies. Consideration of both exercise modalities adds new insights given that we found HIIT to be more effective than SIT in regard to promoting improvements in cognitive function outcomes. Twelve from seventeen (or 71%) of the studies that found benefits utilized high intensity, sub-maximal exercise, rather than all-out effort. The fact that we identified more HIIT than SIT studies probably biased this finding, although dissimilarities in physiological responses such as higher energy expenditure and oxygen uptake, and lower blood lactate concentration for HIIT, may also explain variations in cognitive function.[53] Consistent with evidence for outcomes such as cardiorespiratory fitness,

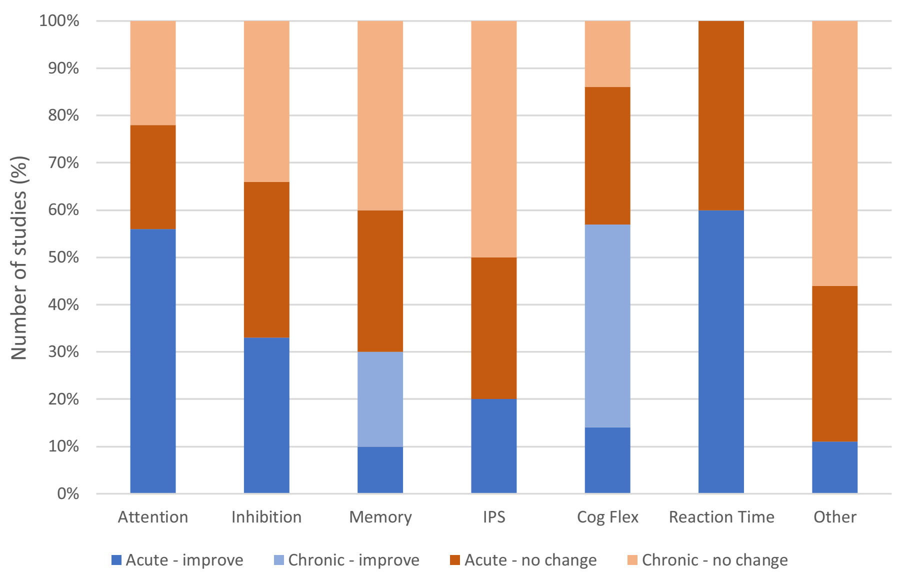

FIGURE 2 Number of acute and chronic training studies showing improvement or no change in cognitive function domains due to HIIT or SIT (IPS: Information Processing Speed).

some inflammatory markers, and muscle structure,[7] it is also interesting to note that four of the twelve HIIT training studies that found positive effects in cognitive function evidenced improvements relative to active controls (i.e., moderate intensity continuous training[31,34,43] or low-intensity exercise/stretching).[17,34,43] While more research is clearly needed, particularly in that these data are biased towards single session training studies, there is some evidence to suggest that HIIT may be a preferrable exercise option for cognitive function benefits.

A novel aim of our review was identification of exercise protocols linked to the settings where HIIT and/or SIT were implemented. Through this we sought to explore the extent to which these exercise modalities have been used in work settings, and if so, whether they benefitted cognitive function domains. We found few studies that reported implementation of a training program outside of the laboratory exercise facility, either at a gym with young, male amateur boxers,[28] at home with older women (68 years of age) who engaged with unsupervised HIIT as part of a 24-week cardiac rehabilitation program,[44] or in an office setting with healthy young men and women (22 years of age), who performed a single session of HIIT as part of a sedentary behavior intervention trial.[29] The two studies implemented in workplace settings (i.e., office and home) found no significant improvements in a range of cognitive function domains when compared to a moderate intensity continuous exercise group, or resting condition.[29,44] Despite these findings, it is too early to formulate a position on potential impact outside of laboratory-based trials, given the very limited number of "in-situ" studies that have investigated effects where work takes place. However, these studies are informative in that they evidence the viability of transitioning and testing high intensity, short duration exercise into post-pandemic hybrid work settings that may include both the home and traditional office.[54] For example, the single group, cross-over trial conducted by Sperlich et al.[29] required participants to undertake office-adapted calisthenic, circuit-based SIT exercises such as squats, skipping and jumping jacks in work clothes. Linked to this, the recent study by Zhang et al.[51] is also of particular interest in highlighting the efficacy of using a telehealth, rather in-person HIIT delivery model. While the authors did not report on intervention acceptability, more studies of this nature are now needed. In this regard, a key recommendation from our review is for researchers and employers to work together to explore the potential of in-person and online HIIT and SIT programs in varied occupational contexts that go beyond the laboratory and exercise facility.

We recognize a number of limitations in presenting the review findings. The search conducted only included studies that were reported in English. It is therefore possible that we may not have identified all published studies in the field. Also, the studies we selected administered 29 different performance measures of cognitive function and a wide range of HIIT and SIT protocols, tested through acute and chronic training trials. While the review provides a valuable overview of trends within the extant evidence base, the heterogeneity of measures and protocols used will have impacted the qualitative synthesis of findings across selected studies to some extent. Strengths included study selection of HIIT/SIT interventions that compared effects against a control group or alternative exercise condition. Unlike other reviews, we also extracted data on intervention setting and a broader range of cognitive function outcomes. In this regard, our review is the first to consider higher quality evidence for HIIT/SIT and cognitive function relative to workplace settings.

5 | CONCLUSIONS

In summary, this review found a body of evidence largely based on studies that have assessed the impact of HIIT/SIT on cognitive function in laboratory-based exercise contexts. Given that half of the studies included in the review evidenced significant intervention effects, and that the level of evidence was of fair-to-good quality, we suggest that transition to testing in "real-world" workplace settings is now warranted. Adoption of common and standardized cognitive function measures by future studies, along with implementation and direct comparison of different HIIT/SIT protocols within the same study design, will be a priority. For "in-situ" studies within work settings, we would also advocate the need for adjunct measures beyond cognitive function tests, that can provide more comprehensive insights into the potential value of HIIT and SIT for worker health, safety, and productivity. This might include assessment of micro-level psychobiological responses to acute stressors, such as those used to measure cortisol and melatonin secretion in office workers using sit-stand and treadmill desks.[55] Employers and other industry stakeholders will also benefit from macro-level evaluation of key performance indicators, or health and safety metrics of groups of workers engaged in high intensity, short duration exercise, across a longitudinal period. This will be important to further investigate potential variations in acute and chronic intervention effects to cognitive function over time.

6 | PERSPECTIVE

High-intensity interval training (HIIT) and sprint interval training (SIT) are ideal intervention strategies for sedentary, time-poor workers given the significant health benefits and low time commitment associated with these types of exercise. However, very little is known about the impact HIIT/SIT has on cognitive function, and therefore, its potential for helping employees navigate work-related tasks successfully, productively, and safely. The review found promising and fair-to-good quality evidence for the benefits of HIIT/SIT on work-related performance measures of cognitive function, with half of the 36 studies reviewed showing acute and chronic training programs improved attention, inhibition, memory, information processing speed, cognitive flexibility, reaction time, intelligence, and learning. Furthermore, this was the first study to review where training studies were implemented, with only four interventions assessing impact in work settings outside of well-controlled laboratory-based environments. Recommendations from the review highlighted that testing intervention programs in ecological valid and varied occupational contexts is now a priority for researchers and employers if the potential benefits of HIIT/SIT are to be fully explored for employee cognitive function, work performance, and health and safety policy.

AUTHOR CONTRIBUTION

All authors were involved in the conception, design, and interpretation of extracted data for the study. DA and ZEP performed the literature search, with NDG also involved in the study selection and data extraction. NDG, ZR, and JJ performed the study quality assessment. NDG was responsible for initial writing and drafting of the paper, which was reviewed and edited by all authors, who approved the final version prior to submission.

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There are no competing interests.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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