Nitrate supplementation improves physical performance specifically in non-athletes during prolonged open-ended tests: a systematic review and meta-analysis

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Abstract

Nitrate (NO₃) is an ergogenic nutritional supplement that is widely used to improve physical performance. However, the effectiveness of NO₃ supplementation has not been systematically investigated in individuals with different physical fitness levels. The present study analysed whether different fitness levels (non-athletes *v*. athletes or classification of performance levels), duration of the test used to measure performance (short *v*. long duration) and the test protocol (time trials *v*. open-ended tests *v*. graded-exercise tests) influence the effects of NO₃ supplementation on performance. This systematic review and meta-analysis was conducted and reported according to the guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement. A systematic search of electronic databases, including PubMed, Web of Science, SPORTDiscus and ProQuest, was performed in August 2017. On the basis of the search and inclusion criteria, fifty-four and fifty-three placebo-controlled studies evaluating the effects of NO₃ supplementation on performance in humans were included in the systematic review and meta-analysis, respectively. NO₃ supplementation open-ended tests (ES 0.47; 95% CI 0.23, 0.71). In contrast, NO₃ supplementation did not enhance the performance of athletes (ES 0.04; 95% CI -0.05, 0.15). After objectively classifying the participants into different performance levels, the frequency of trials showing ergogenic effects in individuals classified at lower levels was higher than that in individuals classified at higher levels. Thus, the present study indicates that dietary NO₃ supplementation improves physical performance in non-athletes, particularly during long-duration open-ended tests.

Key words: Diet: Fitness level: Nitric oxide: Fatigue

Nitrate (NO₃⁻) is an ergogenic nutritional supplement widely consumed by exercise practitioners and athletes to improve their health and physical performance⁽¹⁾. The widespread use of NO₃⁻ likely reflects its abundant availability in many vegetables, and its content ranges from <20 mg/100 g in sweet potato to >250 mg/100 g in beetroot⁽²⁾. Although oral bacteria can reduce NO₃⁻ to nitrite (NO₂⁻), the transit of these foods in the mouth is short, and the resulting increase in NO₃⁻ bioavailability appears to be related to the intrinsic NO₃⁻ content in the vegetable or supplement. Indeed, increased NO₃⁻ bioavailability could favour nitric oxide (NO) synthesis⁽³⁾. NO is a signalling molecule associated with improved cardiovascular and skeletal muscle functions that may potentially enhance physical performance and even facilitate adaptations to exercise training⁽⁴⁾. Nevertheless, the scientific literature provides controversial results regarding the performance-enhancing effects induced by NO_3^- supplementation.

Two systematic reviews and meta-analyses on this topic have recently been published, establishing clear practical recommendations and directions for future studies investigating changes in performance induced by NO₃⁻ supplementation^(5,6). Hoon *et al.*⁽⁵⁾ and McMahon *et al.*⁽⁶⁾ analysed data according to the exercise protocol used (i.e. time trials, open-ended tests and graded-exercise tests) and observed that dietary NO₃⁻ supplementation improved endurance only when performance was evaluated using open-ended tests. Notably, none of these two

Abbreviation: PL, performance level.

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80

60

40

20

Cumulative number of trials (%)

637

brmance 6

Fig. 1. Number of trials (%) reporting that dietary NO_3^- supplementation had no effect (\square) and/or a positive effect (\blacksquare) on physical performance in non-athletes and athletes.

relevance of the present systematic review and meta-analysis, which help clarify the contradictory reports of the effects of NO_3^- supplementation on physical performance.

Therefore, the present study systematically analysed whether different physical fitness levels (i.e. non-athletes v. athletes) influence the effects of NO₃⁻ supplementation on physical performance. In addition, we also evaluated the influence of the duration of the tests used to measure performance (i.e. short v. long duration) and the test protocol used (i.e. time trials v. openended tests v. graded-exercise tests) on the effect of NO₃⁻ supplementation on physical performance in individuals with different physical fitness levels. Thus, the present analyses provide information that is useful to exercise practitioners, athletes, coaches and conditioning professionals who are interested in improving physical performance and achieving health benefits.

Methods

Search strategy

This systematic review and meta-analysis was conducted and reported according to the guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement^(30,31). A systematic search of electronic databases, including PubMed, Web of Science, SPORTDiscus and ProQuest, was performed in August 2017 without any date restrictions. The search strategy was supplemented by manual cross-matching of each publication reference list and key author searches. Combinations of the following keywords were used: effort, endurance, exercise, fatigue, nitrate, nitrate supplementation, nitrite, nitrite supplementation, performance, power, running, speed, sport and workload.

Study selection

Studies that met the following criteria were included in this systematic review and meta-analysis: (i) the participants were healthy humans (either non-athletes or athletes), (ii) physical

meta-analyses divided and analysed separately the studies conducted with athletes or non-athletes, as we are proposing here. McMahon et al. performed a continuous variable metaregression analysis and reported that the fitness level did not have an influence on the ergogenic effect of dietary $NO_3^$ supplementation⁽⁶⁾. However, grouping the data according to the exercise protocol may result in an important bias. In fact, the studies using open-ended tests were mainly performed in non-athletes. In contrast, most studies using time trials were performed in athletes. This disparity might have led to a misinterpretation of the results owing to an unintentional division based on individuals' physical fitness level. Interestingly, neither of the two recent systematic reviews addressed the following question raised by Jonvik et al.: 'Can elite athletes benefit from dietary nitrate supplementation?"(7-9). Therefore, information regarding the effectiveness of NO₃ supplementation in individuals with different physical fitness levels is lacking. Moreover, physical performance is modulated by various mechanisms and depends on several factors, including the duration of the test performed (i.e. short or long duration). Thus, the influence of the test duration on the changes in performance induced by NO₃ supplementation in individuals with different fitness levels remains to be investigated.

Increased NO availability resulting from NO₃ supplementation has beneficial effects on health and physical performance and has been largely studied in humans and laboratory animals. In the central nervous system, NO prevented exaggerated increases in the core body temperature in rats subjected to exercise by increasing cutaneous heat loss and decreasing the metabolic cost of running⁽¹⁰⁻¹³⁾. In these rat studies, the pharmacological blockade of central NO synthesis markedly impaired endurance^(10,12), whereas an increased NO availability in the brain did not affect endurance⁽¹³⁾. In humans, the physical performance benefits mediated by dietary NO3 supplementation have been attributed to peripheral effects, including reduced arterial pressure and VO2. The latter effect leads to a reduced oxygen cost during exercise that is most likely due to the reduced cost of ATP for muscle force production, improved mitochondrial efficiency and increased muscle oxygenation^(14,15). In contrast, the adverse events related to NO₃ supplementation are minor and restricted to red urine (beeturia) and stool, which usually results from the ingestion of beetroot in juice or meals^(16,17).

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Interestingly, both acute and chronic supplementations of NO_3^- have been shown to either improve⁽¹⁸⁻²⁴⁾ or have no effect^(14,25-29) on endurance performance. The uncertain efficacy of NO₃ supplementation appears to be related to the fitness level of the investigated population as demonstrated by a careful evaluation of the cumulative number of trials reporting the performance benefits or lack thereof in both non-athletes (healthy individuals engaged in regular physical activity but not involved in sports competitions) and athletes (Fig. 1). Notably, nearly 65% of the publications on this topic did not report the benefits resulting from NO₃ supplementation. However, if only those studies performed in non-athletes are considered, approximately 45% of the publications show a supplementation-mediated positive effect on physical performance, whereas the percentage of papers showing beneficial effects in athletes is lower than 30% (Fig. 1). Collectively, these observations reinforce the

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performance was measured after the participants were supplemented with NO3 and (iii) the studies were placebocontrolled trials. Furthermore, all included studies were written in English. Reviews, summaries, case studies and letters were not included, although this bibliography was consulted. Studies involving hypoxic conditions, individuals with diseases, exercise in the heat, children and elderly people, and laboratory animals were excluded. On the basis of the search and inclusion/exclusion criteria, fifty-four studies (106 trials) were selected for inclusion in this systematic review, and fifty-three studies (104 trials) were included in the meta-analysis (Fig. 2). Notably, several studies measured more than one physical performance parameter. The data addressing the effect of NO3 supplementation on each parameter were included, and therefore the number of trials was greater than the number of studies. Only one study with one trial⁽²⁰⁾ and one trial in a study with several trials⁽³²⁾ were excluded from the meta-analysis because they did not include the standard deviation data needed to calculate the effect size.

Data grouping

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The selected studies were divided into the following two groups according to the physical fitness level of the individuals tested: non-athletes (forty-three trials) and athletes (sixty-three trials). The individuals were allocated into these two groups according to the classification used by the authors of the research papers, which were consulted. This strategy was efficient in dividing the participants into two groups with different functional capacities as demonstrated by the higher VO2max values in the athletes than in the non-athletes (61.1 (sd 1.8) v. 50.5 (sd 1.8) ml/kg permin; *t*-test, P < 0.05). Similarly, the studies selected for inclusion in the meta-analysis were initially divided into the following two groups: non-athletes (forty-three trials) and athletes (sixty-one trials). The two groups were then subdivided according to the duration of the test performed as follows: short duration (non-athletes, eighteen trials; athletes, seventeen trials) or long duration (non-athletes, twenty-five trials; athletes, forty-four trials). Exercises lasting less than 180 s, thereby characterised by a relevant anaerobic contribution to the energy expenditure, were considered short-duration exercises. Alternatively, exercise bouts lasting more than 180s were considered longduration exercises⁽³³⁾. In addition, because NO₃ supplementation has been shown to have a positive effect on physical performance only in non-athletes during long-duration tests, this group was further subdivided according to the test protocol used (openended tests (constant power), fourteen trials; time trials, four trials; and graded-exercise tests (incremental power), five trials). Open-ended tests consist of exercising at a constant power until the participant is volitionally fatigued; the time until fatigue, which may be highly variable among subjects, is considered the main measure of performance in this test. Finally, owing to the large number of studies in cycling athletes, a specific analysis was conducted for this sport (thirty-seven trials).

Analysis of the relationship between the performance level and the response to NO_3^- supplementation

Because the authors of the research papers may have been imprecise in the classification of their subjects as athletes, we decided to perform an objective analysis. Thus, the individuals were grouped into different performance levels (PL) according to the classification provided by De Pauw *et al.*⁽³⁴⁾. These authors divided the participants in sport science studies into the following five different levels: performance level 1 (PL1) included untrained and sedentary subjects with a VO2max<45.0 ml/kg per min; performance level 2 (PL2) included recreationally trained subjects with a VO_{2max} between 45.0 and 54.9 ml/kg per min; performance level 3 (PL3) included trained subjects with a VO_{2max} between 55.0 and 64.9 ml/kg per min; performance level 4 (PL4) included highly trained subjects with a VO_{2max} between 65.0 and 71.0 ml/kg per min; and performance level 5 (PL5) included professional subjects with a VO_{2max} > 71.0 ml/kg per min. On the basis of this study, we grouped the individuals into five levels and then evaluated the relationship between the PL and the changes in performance induced by NO₃ supplementation.

Risk of bias assessment

Two independent reviewers assessed the risk of bias using an adapted Grading of Recommendations Assessment, Development and Evaluation (GRADE) instrument⁽³⁵⁾. Discrepant evaluations were settled via discussion with a third reviewer. Using this approach, it was possible to evaluate the risk of bias in each study included in the present systematic review. Domains reflecting sequence generation, allocation concealment, blinding of participants and personnel, incomplete outcome data, selective outcome reporting and other sources of bias were evaluated.

Statistical analysis

The mean and standard deviation values of the performance indexes in both the NO₃ supplementation and control trials were obtained from the data provided in the consulted research papers. Heterogeneity was evaluated using the γ^2 test for homogeneity and the I^2 statistic. The effect size (Cohen's d or Hedges' g) was calculated for the performance indexes in each study. Then, a weighted-mean estimate of the effect size was calculated to account for differences in the sample sizes. The mean unweighted effect size and associated 95% CI were also calculated. We used Cohen's classification of the effect size magnitude, where d < 0.20 for negligible effect; d = 0.20 - 0.49for small effect; d = 0.50 - 0.79 for moderate effect; and d > 0.8for large effect⁽³⁶⁾. The χ^2 test was used to compare the frequency of trials showing improved performance in response to NO₃ supplementation among the different PL. Student's t test was used to compare the VO_{2max} between the non-athletes and athletes. Pearson's correlations were performed to evaluate the association between the supplementation parameters (dose, number of days and total amount ingested) and the changes in physical performance. Publication bias was assessed by a visual inspection of funnel plots of the standard error v. effect size⁽³⁷⁾.

Results

Systematic review

In total, 4732 studies were identified through the database and reference searches. After removing the duplicates and



Fig. 2. Summary of the study selection process.

excluding papers that did not meet the eligibility criteria according to a review of their titles, abstracts and full texts, fiftyfour studies (106 trials and 662 individuals) were selected for inclusion in the systematic review (Fig. 2).

The characteristics of the subjects, including information regarding the supplementation regimens and effects of NO₃ supplementation on the physical performance of non-athletes and athletes in each study, are summarised in Tables 1 and 2, respectively. Notably, most studies used beetroot juice as a form of NO₃ supplementation. However, these studies were heterogeneous in several supplementation features, including the ingested volume (70, 140, 250, 280 or 500 ml), dose (between 4.0 and 19.5 mmol), days of supplementation (between 1 and 15 d), timing of supplementation before the trial (between 40 and 1440 min) and the parameter measured to determine physical performance.

Meta-analyses

In total, fifty-three studies (104 trials and 648 individuals) were included in the meta-analysis.

Non-athletes. After pooling the data from forty-three trials, the mean effect size was 0.25 (95% CI 0.11, 0.38), which indicates that the dietary NO_3^- supplementation had a small and significant beneficial effect on physical performance (P < 0.05; Fig. 3). According to a fixed-effects analysis, no heterogeneity

was observed among these studies $(I^2 = 0\%; Q = 15.26, df = 42,$ P = 1.00).

Athletes. After pooling the data from sixty-one trials, the mean effect size was 0.04 (95% CI -0.05, 0.15), which indicates that the dietary NO₃ supplementation had a negligible and nonsignificant effect on improving physical performance (P > 0.05;Fig. 4). According to a fixed-effects analysis, no heterogeneity was observed among these studies ($I^2 = 0\%$; Q = 18.16, df = 60, P=1.00). The subsequent analysis consisted of subdividing both the athletes and non-athletes into those performing shortand long-duration tests.

Non-athletes subjected to short-duration tests. After pooling the data from eighteen trials, the mean effect size was 0.12 (95% CI - 0.07, 0.31), which indicates that the dietary NO₃ supplementation had a negligible and non-significant effect on physical performance (P > 0.05; Fig. 5). According to a fixed-effects analysis, no heterogeneity was observed among these studies $(I^2 = 0\%; Q = 4.43, df = 17, P = 0.99).$

Athletes subjected to short-duration tests. After pooling the data from seventeen trials, the mean effect size was 0.03 (95% CI -0.17, 0.23), which indicates that the dietary NO₃ supplementation had a negligible and non-significant effect on performance (P > 0.05; Fig. 6). According to a random-effects

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						Nitrate supp	olementation					
Deferences	No. of subjects	Characteristics of	VO _{2pea} (ml/kg	_{ak} /VO _{2max} per min)	Ingested fluid/	Dose		Days of	Time before		Variable of physical	Depulto
Reierences	(ð, ¥)	subjects	wean	SD		(mmoi)	Placebo substance	supplementation	that (min)	Exercise protocol	penormance	Results
Aucouturier <i>et al.</i> (1) ⁽³⁸⁾	12 (ð)	Healthy	46.6	3.4	BJ/500	5.4	Apple blackcurrant juice	3	90	Supramaximal intermittent exercise test	Work (kJ)	$S = 168 \cdot 1 (SD \ 60 \cdot 2)$ $NS = 142 \cdot 0 (SD \ 46 \cdot 8)$ D = n0
Aucouturier et al. (2) ⁽³⁸⁾	12 (ð)	Healthy	46.6	3.4	BJ/500	5.4	Apple blackcurrant juice	3	90	Supramaximal intermittent exercise	Time (min)	S = 19.6 (SD 8.1) NS = 16.4 (SD 6.0)
Bailey <i>et al</i> . ⁽¹⁸⁾	8 (ð)	Healthy	49	5	BJ/500	5.5	Blackcurrant cordial without nitrate	6	NR	Severe-intensity exercise	Time (s)	S = 675 (sD 203) NS = 583 (sD 145)
Bailey et al. ⁽¹⁹⁾	7 (ð)	Healthy, recreationally active		-	BJ/500	5.1	Low-energy blackcurrant juice	6	NR	High-intensity exercise	Time (s)	D = yes S = 734 (sd 288) NS = 586 (sd 211)
Bailey <i>et al</i> . (1) ⁽³⁹⁾	7 (ð)	Healthy		-	BJ/70	6.2	Sodium chloride	9	150	Cycling at 35 rpm	Time (s)	S = 344 (SD 74) NS = 341 (SD 99)
Bailey <i>et al.</i> (2) ⁽³⁹⁾	7 (ð)	Healthy		-	BJ/70	6.2	Sodium chloride	9	150	Cycling at 115 rpm	Time (s)	S = 362 (sD 137) NS = 297 (sD 79)
Breese et al. ⁽⁴⁰⁾	9 (4 ð and	Healthy, physically active	♂=3.73 ♀=2.69	♂=0.46* ♀=0.52*	BJ/140	8.0	BJ negligible nitrate content	6	120	Step exercise tests until fatigue	Time (s)	D = yes S = 635 (sd 258) NS = 521 (sd 158)
Buck et al.(41)	- 3 ⊊ <i>)</i> 13 (♀)	Amateur team-sport participants		-	BJ/70	6.0	BJ negligible nitrate content	1	180	3 sessions of 6×20m sprints	Total sprint time (s)	S = 69.8 (SD 4.9) NS = 69.9 (SD 4.1)
Christensen et al. (1) ⁽⁴²⁾	8 (ð)	Recreationally active	46	3	BJ/150	9	Blackcurrant citrus with 0.2 mmol	1	180–249	Incremental leg exercise	Peak power output (W)	S = 304 (SD 34) NS = 310 (SD 47) D = no
Christensen et al. (2) ⁽⁴²⁾	8 (ඊ)	Recreationally active	46	3	BJ/150	9	Blackcurrant citrus with 0.2 mmol	1	180–249	Incremental arm exercise	Peak power output (W)	S = 121 (sp 13) NS = 117 (sp 14)
Coggan <i>et al.</i> (1) ⁽⁴³⁾	12 (7 ð and 5 9)	Healthy		-	BJ/140	11.2	BJ negligible nitrate content	1	120	Knee extensor contractile function (1.57 rad/s)	Peak power output (W/kg)	S = 3.31 (sd 0.55) NS = 3.38 (sd 0.72)
Coggan <i>et al</i> . (2) ⁽⁴³⁾	12 (7 ð and 5 o)	Healthy		-	BJ/140	11.2	BJ negligible nitrate content	1	120	Knee extensor contractile function	Peak power output (W/kg)	S = 5.38 (SD 1.10) NS = 5.48 (SD 1.31)
Coggan <i>et al.</i> (3) ⁽⁴³⁾	12 (7 ♂ and 5 ○)	Healthy		-	BJ/140	11.2	BJ negligible nitrate content	1	120	Knee extensor contractile function	Peak power output	S = 6.76 (SD 1.59) NS = 6.67 (SD 1.73)
Coggan <i>et al.</i> (4) ⁽⁴³⁾	12 (7 ♂ and 5 0)	Healthy		-	BJ/140	11.2	BJ negligible nitrate content	1	120	Knee extensor contractile function	Peak power output (W/kg)	S = 7.64 (sp 1.80) NS = 7.34 (sp 1.87)
Corry et al. ⁽⁴⁴⁾	10 (♂)	Recreationally active		-	BJ/140	8.0	Low-energy blackcurrant juice with negligible NO-	2	40	Wingate test	Mean power output (W/kg)	S = 7.95 (sp 0.55) NS = 7.63 (sp 0.91) D = no
Fulford et al. (1) ⁽⁴⁵⁾	8 (ඊ)	Healthy, physically active		-	BJ/250	10.2	BJ negligible nitrate content	1	150	Isometric maximum voluntary contraction	Mean force of peak contraction (N)	S=368 (sd 90) NS=382 (sd 143)
Fulford <i>et al.</i> (2) ⁽⁴⁵⁾	8 (ð)	Healthy, physically active		-	BJ/250	10.2	BJ negligible nitrate content	5 (2×/d)	150	Isometric maximum voluntary contraction protocol	Mean force of peak contraction (N)	S = 380 (sp 65) NS = 387 (sp 119) D = no
Fulford <i>et al.</i> (3) ⁽⁴⁵⁾	8 (ð)	Healthy, physically active		-	BJ/250	10.2	BJ negligible nitrate content	15 (2×/d)	150	Isometric maximum voluntary contraction protocol	Mean force of peak contraction (N)	S = 408 (SD 110) NS = 365 (SD 115) D = no



Nitrate supplementation

Table 1. Continued

	No. of		VO _{2peal} (ml/kg	VO _{2max}							Variable of	
References	subjects (♂, ♀)	Characteristics of subjects	Mean	SD	Ingested fluid/ volume (ml)	Dose (mmol)	Placebo substance	Days of supplementation	Time before trial (min)	Exercise protocol	physical performance	Results
Kelly <i>et al.</i> (1) ⁽⁴⁶⁾	9 (ð)	Recreationally active	54.5	7.5	BJ/500 (250 + 250)	8.2	BJ negligible nitrate content	7–12	150	Severe-intensity exercise (60% peak	Time (s)	S=696 (sp 120) NS=593 (sp 68)
Kelly <i>et al.</i> (2) ⁽⁴⁶⁾	9 (ð)	Recreationally active	54.5	7.5	BJ/500 (250+250)	8.2	BJ negligible nitrate content	7–12	150	Severe-intensity exercise (70% peak	Time (s)	S = 452 (sp 106) NS = 390 (sp 86)
Kelly <i>et al.</i> (3) ⁽⁴⁶⁾	9 (ð)	Recreationally active	54.5	7.5	BJ/500 (250+250)	8.2	BJ negligible nitrate content	7–12	150	Severe-intensity exercise (80% peak	Time (s)	S = 294 (sp 50) NS = 263 (sp 50) D = ves
Kelly <i>et al.</i> (4) ⁽⁴⁶⁾	9 (ð)	Recreationally active	54.5	7.5	BJ/500 (250+250)	8.2	BJ negligible nitrate content	7–12	150	Severe-intensity exercise (100 % peak	Time (s)	S = 182 (SD 37) NS = 166 (SD 26)
Kokkinoplitis and Chester ⁽⁴⁷⁾	7 (ð)	Healthy		_	BJ/70	6.4	Blackcurrant juice	1	180	Repeated high-intensity sprints (5 × 6 s)	Mean peak power output (W)	S = 4133.5 (SD 674.4) NS = 3938.3 (SD 603.1) D = no
Lansley et al. ⁽²³⁾	9 (ð)	Physically active	55	7	BJ/500	6.2	BJ negligible nitrate content	6	180	Severe-intensity running	Time (min)	S = 8.7 (SD 1.8) NS = 7.6 (SD 1.5) D = ves
Larsen et al. ⁽¹⁵⁾	9 (7 ð and 2 9)	Healthy	3.72	0.33*	Sodium nitrate	0.033 mmol/kg body mass	Sodium chloride	2 (3×/d)	40	Incremental exercise on ergometers	Time (s)	S = 563 (SD 90) NS = 524 (SD 93) D = n0
Mosher <i>et al.</i> ⁽⁴⁸⁾	12 (ð)	Recreationally active		-	BJ/70	6.4	Blackcurrant placebo drink	6	NR	Bench press exercise 3 sets until failure – 60 % 1RM	Total weight lifted (kg)	S = 2582.8 (sp 863.9) NS = 2171.5 (sp 720.5) D = ves
Murphy et al. ⁽⁴⁹⁾	11 (5 ♂ and 6 ♀)	Recreationally fit		-	Baked beetroot	8.0	Cranberry relish	1	60	Time trial 5 km	Running speed (km/h)	S = 12.3 (sp 9.0) NS = 11.9 (sp 8.6)
Nyakayiru et al. ⁽⁵⁰⁾	32 (đ)	Soccer players		-	BJ/140	12·9	BJ negligible nitrate content	6	240	Yo-Yo test	Distance (m)	S = 1623 (SD 48) NS = 1574 (SD 47)
Porcelli <i>et al.</i> (1) ⁽⁵¹⁾	8 (ð)	Healthy individuals with a low aerobic capacity	28.2	-44·1	Sodium nitrate	5.5	Sodium chloride	6	210	Time trial 3 km	Time (s)	S = 886 (SD 74) NS = 910 (SD 82)
Porcelli <i>et al.</i> (2) ⁽⁵¹⁾	7 (ð)	Healthy individuals with a moderate aerobic capacity	45.5	-57.1	Sodium nitrate	5.5	Sodium chloride	6	210	Time trial 3 km	Time (s)	S = 723 (sp 90) NS = 734 (sp 93) D = ves
Porcelli <i>et al.</i> (3) ⁽⁵¹⁾	6 (ð)	Healthy individuals with a high aerobic capacity	63·9	-81.7	Sodium nitrate	5.5	Sodium chloride	6	210	Time trial 3 km	Time (s)	S = 627 (SD 30) NS = 629 (SD 28) D = no
Rienks et al. ⁽⁵²⁾	10 (Չ)	Healthy	37.1	5.3	BJ/140	12.9	BJ negligible nitrate content	1	150	20 min of cycling exercise at RPE 13	Total mechanical work (kJ)	S = 30.3 (SD 5.3) NS = 29.8 (SD 6.1) D = no
Thompson et al. ⁽⁵³⁾	16 (ð)	Healthy, recreationally active	47.3	6.3	BJ/500	5.0	BJ negligible nitrate content	1	90	Continuous cycle exercise test until volitional exhaustion	Exercise tolerance (s)	S = 185 (sp 122) NS = 160 (sp 109) D = ves
Thompson et al. ⁽⁵⁴⁾	16 (ð)	Recreational team- sport players	50	7	BJ/70	6.4	BJ negligible nitrate content	7 (2×/d)	150	Intermittent-sprint test	Total work done during the sprints (k.l)	S = 123 (sp 19) NS = 119 (sp 17) D = ves
Vanhatalo et al. ⁽¹⁶⁾	8 (5 ♂ and 3 ♀)	Healthy		-	BJ/500	5.2	Low-energy blackcurrant juice cordial with low nitrate	15 (2×/d)	150–180	Incremental cycling test	Peak power output (W)	S = 323 (sp 68) NS = 331 (sp 68) D = yes
Vasconcellos et al. ⁽⁵⁵⁾	25 (14 ♂ and 11 ♀)	Healthy	♂=64·31 ♀=52·79	♂=4.71 ♀=4.57	Two beetroot gels with 50 g each and 300 ml of water	9.92 (sd 1.97)	Placebo gel	1	90	Severe-intensity running	Time (s)	S = 395.4 (sp 179.6) NS = 390.9 (sp 158.5) D = no

Table 1. Continued

						Nitrate supple	ementation					
	No. of		VO _{2pea} (ml/kg	_{ak} /VO _{2max} per min)	- la se sta d'élaid/	Dees		Davis of	Time hafens		Variable of	
References	subjects (♂, ♀)	subjects	Mean	SD	volume (ml)	Dose (mmol)	Placebo substance	supplementation	trial (min)	Exercise protocol	physical performance	Results
Wylie <i>et al.</i> (1) ⁽¹⁷⁾	10 (ð)	Healthy, recreationally active		-	BJ/70	4.2	Water	1	150	Severe-intensity cycling exercise	Time (s)	S=508 (sp 102) NS=470 (sp 81) D=no
Wylie <i>et al.</i> (2) ⁽¹⁷⁾	10 (ð)	Healthy, recreationally active		-	BJ/140	8.4	Water	1	150	Severe-intensity cycling exercise	Time (s)	S = 570 (sp 153) NS = 498 (sp 113) D = ves
Wylie <i>et al.</i> (3) ⁽¹⁷⁾	10 (ð)	Healthy, recreationally active		-	BJ/280	12.8	Water	1	150	Severe-intensity cycling exercise	Time (s)	S = 552 (sp 117) NS = 493 (sp 114) D = ves
Wylie <i>et al</i> . ⁽⁵⁶⁾	14 (ð)	Recreational team-sport players	52	7	BJ/140	4.1	BJ negligible nitrate content	2	150	Yo-Yo IR1	Distance covered (m)	S = 1704 (sp 304) NS = 1636 (sp 288) D = ves
Wylie <i>et al.</i> (1) ⁽⁵⁷⁾	10 (ඊ)	Recreational team-sport players	58	8	BJ/140	8.2	BJ negligible nitrate content	3	150	Maximal efforts (24×6-s protocol)	Mean power output (W)	S = 568 (sp 136) NS = 539 (sp 136)
Wylie <i>et al.</i> (2) ⁽⁵⁷⁾	10 (ð)	Recreational team- sport players	58	8	BJ/140	8.2	BJ negligible nitrate content	4	150	Maximal efforts (7 × 30-s protocol)	Mean power output (W)	S = 558 (sp 95) NS = 562 (sp 94)
Wylie <i>et al.</i> (3) ⁽⁵⁷⁾	10 (ð)	Recreational team- sport players	58	8	BJ/140	8.2	BJ negligible nitrate content	5	150	Maximal efforts (6 × 60-s protocol)	Mean power output (W)	S = 374 (sp 57) NS = 375 (sp 59) D = no

 $_{\mathcal{J}}$, Male; φ , female; BJ, beetroot juice; NR, not reported; S, supplemented; NS, no supplementation; D, statistical difference. * Absolute VO₂ data in l/min.

Nitrate supplementation

			VO	_{2peak} / (ml/kg	/ //kg							
References	No. of subjects (♂, ♀)	Characteristics of subjects	Mean	min)	Ingested fluid/ volume (ml)	Dose (mmol)	Placebo substance	Days of supplementation	Time before trial (min)	Exercise protocol	Measure of physical performance	Results
Bescós et al. ⁽²⁶⁾	11 (ð)	Cyclists and triathletes	65.1	6.2	Sodium nitrate/250	11.8	Sodium chloride	1	180	Incremental exercise	Time (s)	S=416 (sp 32) NS=409 (sp 27)
Bescós <i>et al.</i> (1) ⁽²⁵⁾	13 (ð)	Cyclists and triathletes		-	Sodium nitrate/250	11.6	Sodium chloride	3	180	Distance trial (40 min) in cycle ergometer	Distance (km)	D = no S = 26.4 (sd 1.1) NS = 26.3 (sd 1.2)
Bescós <i>et al.</i> (2) ⁽²⁵⁾	13 (ð)	Cyclists and triathletes		-	Sodium nitrate/250	11.6	Sodium chloride	3	180	Distance trial (40 min) in cycle ergometer	Mean power output (W)	D = 10 S = 258 (sd 28) NS = 257.3 (sd 28)
Bond et al. ⁽²⁰⁾	14 (ð)	Rowers		-	BJ/500 (250+250)	5.0	Blackcurrant juice	6	NR	6 × 500 m rowing – ergometer repetitions	Time (s)	D = no S = 89.4 NS = 90.1
Boorsma <i>et al.</i> $(1)^{(58)}$	8 (ð)	Distance runners	80	5	BJ/210 (on the test day) and 140 (other days)	19.5	BJ negligible nitrate content	1	150	Time trial 1500 m	Time (s)	D = n0 S = 250.7 (sd 4.3) NS = 250.4 (sd 7.0) D = n0
Boorsma <i>et al.</i> (2) ⁽⁵⁸⁾	8 (ඊ)	Distance runners	80	5	BJ/210 (on the test day) and 140 (other days)	19.5 (on the test day) and 13 (other days)	BJ negligible nitrate content	8	150	Time trial 1500 m	Time (s)	S = 250.5 (sp 6.2) NS = 251.4 (sp 7.6) D = no
Callahan <i>et al.</i> (1) ⁽⁵⁹⁾	8 (ð)	Endurance-trained cyclists	65·2	4.2	Gelatine capsules + water (400 ml)	5.0	Gelatine capsules (90 % BeetEssence and 10 % Black Cherry	3	60	Time trial 4000 m	Mean power output (W)	S = 388 (SD 54) NS = 386 (SD 56) D = no
Callahan <i>et al.</i> (2) ⁽⁵⁹⁾	8 (ð)	Endurance-trained cyclists	65·2	4.2	Gelatine capsules + water (400 ml)	5.0	Gelatine capsules (90 % Beet Essence and 10 % Black Cherry	3	60	Time trial 4000 m	Time (s)	S = 337.4 (sd 17.1) NS = 338.1 (sd 18.0)
Cermak et al. (1) ⁽²¹⁾	12 (ð)	Cyclists and triathletes	58	2	BJ/140 (70+70)	8.0	BJ negligible nitrate content	6	150	Time trial 10 km	Time (s)	D = 10 S = 953 (sd 72.5) NS = 965 (sd 72.5) D = vec
Cermak et al. (2) ⁽²¹⁾	12 (ð)	Cyclists and triathletes	58	2	BJ/140 (70+70)	8.0	BJ negligible nitrate content	6	150	Time trial 10 km	Mean power output (W)	D = yes S = 294 (sD 41.5) NS = 288 (sD 41.5) D = yes
Cermak <i>et al.</i> (1) ⁽²⁷⁾	20 (ථ)	Cyclists or triathletes	60	1	BJ/140	8.7	BJ negligible nitrate content	1	150	Time trial approximately 1073 kJ	Time (min)	S = 65.5 (sD 4.8) NS = 65.0 (sD 4.8)
Cermak <i>et al.</i> (2) ⁽²⁷⁾	20 (ථ)	Cyclists or triathletes	60	1	BJ/140	8.7	BJ negligible nitrate content	1	150	Time trial approximately 1073 kJ	Mean power output (W)	S = 275 (sd 30.9) NS = 278 (sd 30.9)
Christensen et al. (1) ⁽³²⁾	10 (ð)	Cyclists	72·1	4.5	BJ/500	8.0	Apple and blackcurrant juice	4	180	Repeated sprint test (6, 20 s)	Mean power output (W)	S = 630 (SD 84) NS = 630 (SD 92)
Christensen et al. (2) ⁽³²⁾	10 (ð)	Cyclists	72·1	4.5	BJ/500	8.0	Apple and blackcurrant juice	6	180	Time trial 1677 kJ (400 kcal)	Time (min)	S = 18·33 NS = 18·61
Christensen et al. (3) ⁽³²⁾	10 (ð)	Cyclists	72·1	4.5	BJ/500	8.0	Apple and blackcurrant juice	6	180	Time trial 1677 kJ (400 kcal)	Mean power output (W)	S = 290 (sp 43) NS = 285 (sp 44)
Christensen et al. (3) ⁽⁴²⁾	9 (ð)	Endurance-trained cyclists	64	3	BJ/150	9	Blackcurrant citrus with 0.2 mmol nitrate	1	180–249	Incremental leg exercise	Peak power output (W)	S = 418 (sp 47) NS = 406 (sp 46)
Christensen et al. (4) ⁽⁴²⁾	9 (ð)	Endurance-trained cyclists	64	3	BJ/150	9	Blackcurrant citrus with 0.2 mmol nitrate	1	180–249	Incremental arm exercise	Peak power output (W)	S = 140 (SD 17) NS = 141 (SD 20)
Glaister et al. ⁽⁶⁰⁾	14 (♀)	Cyclists and triathletes	52.3	4.9	BJ/70	7.3	BJ negligible nitrate content	1	150	Time trial 20 km	Time (min)	S = 35.3 (sp 1.5) NS = 35.3 (sp 1.7)
Hoon <i>et al.</i> (1) ⁽⁶¹⁾	28 (ð)	Cyclists		-	BJ/70	4·1	BJ negligible nitrate content	1	75	Time trial 4 min	Mean power output (W)	S = 403 (SD 52) NS = 396 (SD 57) D = no

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Table 2. Continued

				Nitrate supplementation									
	No. of		VO _{2ma} per	_{2peak} / _{ix} (ml/kg min)	Indested fluid/			Dave of	Time before		Measure of		
References	(♂, ♀)	Characteristics of subjects	Mean	SD	volume (ml)	Dose (mmol)	Placebo substance	supplementation	trial (min)	Exercise protocol	performance	Results	
Hoon <i>et al.</i> (2) ⁽⁶¹⁾	28 (ð)	Cyclists		-	BJ/70	4.1	BJ negligible nitrate content	1	150	Time trial 4 min	Mean power output (W)	S = 402 (sp 47 NS = 396 (sp 57)	
Hoon <i>et al.</i> (1) ⁽⁶²⁾	10 (ð)	Rowers		-	BJ/70	4.2	BJ negligible nitrate content	1	120	Time trial 2000 m	Time (s)	S = 383.4 (sd 8.7) NS = 383.5 (sd 9)	
Hoon <i>et al.</i> (2) ⁽⁶²⁾	10 (ð)	Rowers		-	BJ/140	8.4	BJ negligible nitrate content	1	120	Time trial 2000 m	Time (s)	S = 381.9 (sd 9) NS = 383.5 (sd 9)	
Kramer <i>et al.</i> (1) ⁽⁶³⁾	12 (_ð)	CrossFit	48·5	7.0	Potassium nitrate	8.0	Nitrate-free potassium chloride	6	1440	Wingate test	Wingate peak	D = yes S = 948.0 (sp 186.8) NS = 905.0 (sp 157.2) D = yes	
Kramer <i>et al.</i> (2) ⁽⁶³⁾	12 (_ð)	CrossFit	48.5	7.0	Potassium nitrate	8.0	Nitrate-free potassium chloride	6	1440	Time trial 2 km	Time (s)	S = 459.7 (sp 23.9) NS = 459.8 (sp 24.8) D = no	
Lane <i>et al.</i> (1) ⁽⁶⁴⁾	12 (ở)	Cyclists and triathletes	71·6	4.6	BJ/70	8.4	BJ negligible nitrate content	2	130	Time trial 43.83 km	Time (min)	S = 64.0 (SD 2.8) NS = 63.5 (SD 3.2) D = no	
Lane <i>et al.</i> (2) ⁽⁶⁴⁾	12 (ð)	Cyclists and triathletes	71·6	4.6	BJ/70	8.4	BJ negligible nitrate content	2	130	Time trial 43.83 km	Power output (W)	S = 298 (sp 35 NS = 303 (sp 41) D = no	
Lane <i>et al.</i> (3) ⁽⁶⁴⁾	12 (<u></u>)	Cyclists and triathletes	59.9	5.1	BJ/70	8.4	BJ negligible nitrate content	2	130	Time trial 29.35 km	Time (min)	S = 51.6 (sp 2.6) NS = 51.6 (sp 2.5)	
Lane <i>et al.</i> (4) ⁽⁶⁴⁾	12 (Չ)	Cyclists and triathletes	59.9	5.1	BJ/70	8.4	BJ negligible nitrate content	2	130	Time trial 29.35 km	Power output (W)	S = 207 (sp 31) NS = 207 (sp 29)	
Lansley <i>et al</i> . (1) ⁽²²⁾	9 (ð)	Cyclists	56.0	5.7	BJ/500	6.2	BJ negligible nitrate content	1	120	Time trial 4 km	Time (min)	S = 6.27 (sD 0.35) NS = 6.45 (sD 0.42)	
Lansley <i>et al.</i> (2) ⁽²²⁾	9 (ð)	Cyclists	56.0	5.7	BJ/500	6.2	BJ negligible nitrate content	1	120	Time trial 4 km	Mean power output (W)	S = 292 (sD 44) NS = 279 (sD 51)	
Lansley <i>et al.</i> (3) ⁽²²⁾	9 (ð)	Cyclists	56.0	5.7	BJ/500	6.2	BJ negligible nitrate content	1	120	Time trial 16.1 km	Time (min)	S = 26.9 (sD 1.8) NS = 27.7 (sD 2.1)	
Lansley <i>et al.</i> $(4)^{(22)}$	9 (ð)	Cyclists	56.0	5.7	BJ/500	6.2	BJ negligible nitrate content	1	120	Time trial 16.1 km	Mean power output (W)	S = 247 (sp 44 NS = 233 (sp 43)	
Lowings et al. ⁽⁶⁵⁾	10 (5 ♂ and 5 ♀)	Swimmers		-	BJ/140 (70+70)	12.5	BJ negligible nitrate content	1	180	Swim time trial 168 m	Time (s)	S = 130.3 (SD 8.1) NS = 131.5 (SD 9.0) D = ves	
Martin <i>et al</i> . (1) ⁽⁶⁶⁾	16 (9 ♂ and 7 0)	Team-sport players	47.2	8.5	BJ/70	4.83	BJ negligible nitrate content	1	120	8-s bouts of high-intensity intermittent-sprint test	No. of sprints completed	S = 13 (SD 5) NS = 15 (SD 6)	
Martin <i>et al.</i> (2) ⁽⁶⁶⁾	16 (9 ♂ and 7 9)	Team-sport players	47.2	8.5	BJ/70	4.83	BJ negligible nitrate content	1	120	8-s bouts of high-intensity intermittent-sprint test	Work (kJ)	S = 49.2 (sp 24.2) NS = 57.8 (sp 34.0)	
Martin <i>et al.</i> (3) ⁽⁶⁶⁾	16 (9 ♂ and 7 ○)	Team-sport players	47.2	8.5	BJ/70	4.83	BJ negligible nitrate content	1	120	8-second bouts of high- intensity intermittent-	Mean power output (W)	S = 447 (sp 104) NS = 444 (sp 117)	
McQuillan et al. (1) ⁽⁶⁷⁾	9 (ð)	Cyclists	68	3	BJ/140	8.0	BJ negligible nitrate content	4	150	Time trial 1 km	Time (s)	S = 79.6 (sD 3.5) NS = 79.2 (sD 2.9)	
McQuillan et al. (2) ⁽⁶⁷⁾	9 (ð)	Cyclists	68	3	BJ/140	8.0	BJ negligible nitrate content	4	150	Time trial 1 km	Mean power output (W)	S = 495 (SD 61) NS = 503 (SD 51) D = no	

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Nitrate supplementation

Table 2. Continued

			VO;	peak/								
	No. of		VO _{2ma} per	x (ml/kg min)							Measure of	
References	subjects (♂, ♀)	Characteristics of subjects	Mean	SD	Ingested fluid/ volume (ml)	Dose (mmol)	Placebo substance	Days of supplementation	trial (min)	Exercise protocol	physical performance	Results
McQuillan et al. (3) ⁽⁶⁷⁾	9 (ð)	Cyclists	68	3	BJ/140	8.0	BJ negligible nitrate content	7	150	Time trial 1 km	Time (s)	S = 79.3 (SD 3.3) NS = 79.0 (SD 3.0)
McQuillan et al. (4) ⁽⁶⁷⁾	9 (ð)	Cyclists	68	3	BJ/140	8.0	BJ negligible nitrate content	7	150	Time trial 1 km	Mean power output (W)	S = 501 (sp 59) NS = 505 (sp 52) D = po
McQuillan et al. (5) ⁽⁶⁷⁾	9 (ð)	Cyclists	68	3	BJ/140	8.0	BJ negligible nitrate content	3	150	Time trial 4 km	Time (s)	S = 341 (sp 12) NS = 340 (sp 10) D = po
McQuillan et al. (6) ⁽⁶⁷⁾	9 (ð)	Cyclists	68	3	BJ/140	8.0	BJ negligible nitrate content	3	150	Time trial 4 km	Mean power output (W)	S = 390 (sD 45) NS = 393 (sD 37) D = n0
McQuillan et al. (7) ⁽⁶⁷⁾	9 (ð)	Cyclists	68	3	BJ/140	8.0	BJ negligible nitrate content	6	150	Time trial 4 km	Time (s)	S = 340 (SD 10) NS = 340 (SD 11) D = n0
McQuillan et al. (8) ⁽⁶⁷⁾	9 (ð)	Cyclists	68	3	BJ/140	8.0	BJ negligible nitrate content	6	150	Time trial 4 km	Mean power output (W)	S = 394 (sp 38) NS = 393 (sp 37) D = no
McQuillan <i>et al</i> . (1) ⁽⁶⁸⁾	8 (ð)	Cyclists	63	4	BJ/70	4.0	BJ negligible nitrate content	8	120	Time trial 4 km	Time (s)	S=343.6 (sp 14.3) NS=344.8 (sp 14.0) D=no
McQuillan et al. (2) ⁽⁶⁸⁾	8 (ð)	Cyclists	63	4	BJ/70	4.0	BJ negligible nitrate content	8	120	Time trial 4 km	Mean power output	S = 380 (sp 41) NS = 375 (sp 40) D = no
Muggeridge <i>et al</i> . (1) ⁽⁶⁹⁾	8 (ð)	Kayakers	49.0	6.1	BJ/70	5.0	Tomato juice	1	180	Steady-state paddling at 60 % of WR _{max} (15 min)	Mean power output (W)	S = 108 (SD 64.8) NS = 108 (SD 62.0) D = n0
Muggeridge <i>et al.</i> (2) ⁽⁶⁹⁾	8 (ð)	Kayakers	49.0	6.1	BJ/70	5.0	Tomato juice	1	180	Time trial 1 km	Time (s)	S = 276 (sp 14·1) NS = 277 (sp 14·1) D = no
Nyakayiru et al. ⁽⁷⁰⁾	17 (ð)	Cyclists and triathletes	65∙0	4.0	Sodium nitrate/140	12.9	Sodium chloride	6	240	Time trial 10 km	Time (s)	S = 1004 (SD 67) NS = 1017 (SD 71) D = n0
Peacock et al. ⁽²⁸⁾	10 (ð)	Elite cross-country skiers	69.6	5.1	1 g of potassium nitrate in a capsule	9.9	1 g of maltodextrin in a capsule	1	150	Time trial 5 km	Time (s)	S = 1005 (SD 53) NS = 996 (SD 49) D = no
$\begin{array}{c} \text{Peeling et al.} \\ (1)^{(71)} \end{array}$	6 (ð)	Kayakers	57.15	2.77	BJ/70	4.8	BJ negligible nitrate content	1	150	4-min all-out maximal effort on the stationary kayak ergometer	Power output (W)	$S = 319 (s_D 35)$ NS = 318 (s_D 42) D = no
Peeling <i>et al.</i> (2) ⁽⁷¹⁾	6 (ð)	Kayakers	57.15	2.77	BJ/70	4.8	BJ negligible nitrate content	1	150	4-min all-out maximal effort on the stationary kayak ergometer	Distance covered (m)	S = 989 (sp 31) NS = 982 (sp 36) D = no
Peeling <i>et al.</i> (3) ⁽⁷¹⁾	5 (Ŷ)	Kayakers	47.8	3.7	BJ/70	9.6	BJ negligible nitrate content	1	120	Time trial 500 m	Time (s)	S = 114.6 (SD 1.5) NS = 116.7 (SD 2.2) D = ves
Peeling <i>et al.</i> (4) ⁽⁷¹⁾	5 (Ŷ)	Kayakers	47.8	3.7	BJ/70	9.6	BJ negligible nitrate content	1	120	Time trial 500 m	Velocity in 100– 400 m (m/s)	S = 4.4 (sp 0.03) NS = 4.3 (sp 0.05) D = ves
Rimer <i>et al.</i> (1) ⁽⁷²⁾	13 (11 ♂ and 2 ♀)	Tennis, Alpine Ski, American Football, Cycling, Triathlon		-	BJ/140 (70+70)	11.2	BJ negligible nitrate content	1	150	4×, maximal inertial-load cycling trial (3-4 s)	Maximal power output (W)	S = 1229 (SD 317) NS = 1213 (SD 300) D = VeS
Rimer <i>et al.</i> (2) ⁽⁷²⁾	13 (11 ♂ and 2 ♀)	Tennis, Alpine Ski, American Football, Cycling, Triathlon		_	BJ/140 (70+70)	11.2	BJ negligible nitrate content	1	150	Maximal isokinetic cycling trial, 120 rpm (30 s)	Total work (kJ)	S = 22.8 (sp 4.8) NS = 23.0 (4.4) D = no
Rimer et al. ⁽⁷³⁾	13 (11 ♂ and 2 ♀)	Tennis, Alpine Ski, American Football, Cycling, Triathlon		-	BJ/140 (70+70)	11.2	BJ negligible nitrate content	1	150	Maximal isokinetic cycling trial, 120 rpm (30 s)	Peak Power (W)	S = 1173 (sp 255) NS = 1185 (sp 249) D = no



Table 2. Continued

		f		Nitrate supplementation								
	No. of		VO VO _{2ma} per	_{²peak} / _{¤x} (ml/kg ∵min)	Ingested fluid/			Davia of	Time before		Measure of	
References	(♂, ♀)	Characteristics of subjects	Mean	SD	volume (ml)	Dose (mmol)	Placebo substance	supplementation	trial (min)	Exercise protocol	performance	Results
Shannon <i>et al.</i> (1) ⁽⁷⁴⁾	8 (ð)	Runners or triathletes	62-3	8.1	BJ/140	12.5	BJ negligible nitrate content	1	180	Time trial 1⋅500 m	Time (s)	S=319.6 (SD 36.2) NS=325.7 (SD 38.8)
Shannon <i>et al.</i> (2) ⁽⁷⁴⁾	8 (ð)	Runners or triathletes	62·3	8.1	BJ/140	12.5	BJ negligible nitrate content	1	180	Time trial 10.000 m	Time (s)	D = yes S = 2643·1 (sp 324·1) NS = 2649·9 (sp 319·8)
Thompson <i>et al</i> . (1) ⁽⁷⁵⁾	36 (ð)	Team-sport players		-	BJ/70	6.4	BJ negligible nitrate content	5	150	Sprints (5×20 m)	Time (s) at 20 m	D = n0 S = 3.98 (sp 0.18) NS = 4.03 (sp 0.19)
Thompson <i>et al</i> . (2) ⁽⁷⁵⁾	36 (ð)	Team-sport players		-	BJ/70	6.4	BJ negligible nitrate content	5	150	Teste Yo-Yo IR1 (2×20m)	Distance covered (m)	D = yes S = 1422 (sD 502) NS = 1369 (sD 505) D = yes
Wilkerson <i>et al.</i> (1) ⁽⁷⁶⁾	8 (ඊ)	Cyclists	63	8	BJ/500	6.2	BJ negligible nitrate content	1	150	Time trial 50 miles	Time (min)	S = 136.7 (sD 5.6) NS = 137.9 (sD 6.4)
Wilkerson et al. (2) ⁽⁷⁶⁾	8 (ð)	Cyclists	63	8	BJ/500	6.2	BJ negligible nitrate content	1	150	Time trial 50 miles	Mean power output (W)	S = 238 (sp 22) NS = 235 (sp 27) D = no

d, Male; ♀, female; BJ, beetroot juice; NR, not reported; S, supplemented; NS, no supplementation; D, statistical difference.

Christensen et al. (1) ⁽⁴²⁾ Vanitatio et al. (1) ⁽⁴³⁾ Coggan et al. (1) ⁽⁴³⁾ Coggan et al. (2) ⁽⁴³⁾ Fullor et al. (2) ⁽⁴³⁾ Fullor et al. (2) ⁽⁴³⁾ Fullor et al. (2) ⁽⁴³⁾ Fullor et al. (2) ⁽⁴³⁾ Coggan et al. (3) ⁽⁵⁷⁾ Fullor et al. (3) ⁽⁵⁷⁾ Coggan et al. (3) ⁽⁵⁷⁾ Coggan et al. (3) ⁽⁵⁷⁾ Coggan et al. (3) ⁽⁵⁷⁾ Coggan et al. (3) ⁽⁴³⁾ Coggan et al. (3) ⁽⁴⁴⁾ Coggan et al. (3) ⁽⁴⁴⁾ Coggan et al. (3) ⁽⁴⁵⁾ Coggan et al. (4) ⁽⁴³⁾ Coggan et al	Study	SMD	95 % CI	Weight (%)
Vanhatio et al. (196) $-0.12 - 11.0 + 0.66$ 182 Fulford et al. (1) ⁴⁵⁰ $-0.12 - 11.0 + 0.69$ 182 Coggan et al. (2) ⁴⁵⁰ $-0.08 - 0.88 + 0.72$ 2.73 Fulford et al. (2) ⁴⁵⁰ $-0.04 - 0.92 + 0.83$ 2.28 Buck et al. (1) $-0.04 - 0.92 + 0.83$ 2.28 Buck et al. (1) $-0.04 - 0.92 + 0.83$ 2.28 Buck et al. (1) $-0.01 - 0.79 + 0.78$ 2.45 Bailey et al. (1) ⁽⁵⁰⁾ $-0.02 - 0.89 + 0.66$ 2.28 Vacconcilos et al. (50) $-0.01 - 0.79 + 0.78$ 2.45 Bailey et al. (1) ⁽⁵⁰⁾ $-0.01 - 0.79 + 0.78$ 2.45 Decode tal. (3) (51) $0.05 - 0.75 + 0.68$ 2.51 Porcelli et al. (3) (51) $0.07 - 1.06 + 1.20$ 1.37 Porcelli et al. (3) (51) $0.07 - 1.06 + 0.97$ 2.73 Porcelli et al. (1) (57) $0.22 - 0.48 + 0.91$ 3.63 Thompson et al. (66) $0.22 - 0.48 + 0.91$ 3.63 Thompson et al. (50) $0.22 - 0.48 + 0.91$ 3.63 Thompson et al. (50) $0.22 - 0.48 + 0.91$ 3.63 Thompson e	Christensen et al. (1) ⁽⁴²⁾	-0.12	–1·13, 0·84	1.82
Fulford et al. (1) ⁽⁴³⁾ Coggan et al. (2) ⁽⁴³⁾ -012 -110, 0-86 1-82 Coggan et al. (2) ⁽⁴³⁾ -008 -0-88, 0-72 2-73 Fulford et al. (2) ⁽⁴⁵⁾ -004 -0-92, 0-83 2-28 Buck et al. ⁽⁴¹⁾ -003 -0-53, 0-48 6-64 Wylie et al. (2) ⁽⁵⁷⁾ -004 -0-92, 0-83 2-28 Bailey et al. (1) ⁽⁵⁹⁾ -004 -0-92, 0-83 2-28 Bailey et al. (1) ⁽⁵⁹⁾ -004 -0-92, 0-83 2-28 Coggan et al. (2) ⁽⁵⁷⁾ -004 -0-92, 0-83 2-28 Coggan et al. (2) ⁽⁵⁷⁾ -004 -0-92, 0-83 2-28 Coggan et al. (2) ⁽⁵⁷⁾ -004 -0-92, 0-83 2-28 Coggan et al. (2) ⁽⁵⁷⁾ -004 -0-92, 0-83 2-28 Coggan et al. (3) ⁽⁵¹⁾ -005 -0-78, 0-88 2-28 Coggan et al. (3) ⁽⁵¹⁾ -005 -0-78, 0-88 2-28 Coggan et al. (3) ⁽⁵¹⁾ -005 -0-78, 0-88 2-28 Coggan et al. (3) ⁽⁵¹⁾ -005 -0-78, 0-88 2-28 Coggan et al. (3) ⁽⁵¹⁾ -005 -0-78, 0-88 2-28 Coggan et al. (3) ⁽⁵¹⁾ -005 -0-78, 0-88 2-28 Coggan et al. (3) ⁽⁵¹⁾ -005 -0-78, 0-88 2-28 Coggan et al. (3) ⁽⁵¹⁾ -005 -0-78, 0-88 2-28 Coggan et al. (3) ⁽⁵¹⁾ -005 -0-78, 0-88 2-28 Coggan et al. (3) ⁽⁵¹⁾ -005 -0-78, 0-88 2-28 Coggan et al. (3) ⁽⁵¹⁾ -005 -0-78, 0-88 2-28 Coggan et al. (3) ⁽⁵¹⁾ -005 -0-78, 0-88 2-28 Coggan et al. (3) ⁽⁵¹⁾ -005 -0-78, 0-88 2-28 Coggan et al. (3) ⁽⁵¹⁾ -005 -0-78, 0-88 2-28 Coggan et al. (2) ⁽⁵¹⁾ -007 -06, 1-29 2-73 Coggan et al. (2) ⁽⁴²⁾ -008 -044 -04 2-2 Coggan et al. (2) ⁽⁴²⁾ -008 -044 -04 2-2 Coggan et al. (2) ⁽⁴²⁾ -008 -044 -04 -04 -04 -04 -04 -04 -04 -04 -0	Vanhatalo et al. (16)	-0.12	-1·10, 0·86	1.82
Coggan et al. (1) ⁽⁴³⁾ -0.11 - 0.91, 0.69 2.73 Coggan et al. (2) ⁽⁴³⁾ -0.06 -0.88, 0.72 2.73 Wylie et al. (2) ⁽⁴⁵⁾ -0.07 -0.08, 0.68 2.73 Wylie et al. (3) ⁽⁵⁷⁾ -0.04 -0.92, 0.83 2.28 Buck et al. (4) ⁽⁴³⁾ -0.02 -0.80, 0.68 2.28 Vasconcellos et al. (50) -0.01 -0.79, 0.78 2.85 Drocell et al. (3) ⁽⁵⁷⁾ -0.02 -0.80, 0.86 2.28 Vasconcellos et al. (30) -0.01 -0.79, 0.78 2.85 Coggan et al. (3) ⁽⁴³⁾ 0.05 -0.75, 0.85 2.71 Porcell et al. (2) ⁽⁵¹⁾ 0.07 -1.06, 1.20 1.37 Teineks et al. ⁽²²⁾ 0.08 0.02 -0.64, 1.01 2.05 Coggan et al. (4) ⁽⁴³⁾ 0.06 -0.75, 0.85 2.74 Porcelli et al. (1) ⁽⁵⁷⁾ 0.16 -0.64, 0.97 2.73 Wylie et al. (2) ⁽⁵¹⁾ 0.07 -1.06, 1.20 1.37 Thompson et al. ⁽⁵⁶⁾ 0.22 -0.44, 0.95 3.62 Wylie et al. (1) ⁽⁵⁷⁾ 0.22 -0.44, 0.95 3.62 Chyl	Fulford et al. (1) ⁽⁴⁵⁾	-0.12	-1.10, 0.86	1.82
Cogan et al. (2) ⁽⁴⁵⁾ -008 -086 0.72 2.73 Fullor et al. (2) ⁽⁴⁵⁾ -007 -005.091 1.82 Buck et al. ⁽⁴¹⁾ -003 -053.048 6.84 Wylie et al. (3) ⁽⁵⁷⁾ -007 -053.091 1.82 Vasconcellos et al. ⁽⁶⁵⁾ -001 -079.078 2.85 Bailey et al. (1) ⁽⁶⁹⁾ 003 -075.088 2.51 Cogan et al. (3) ⁽⁴³⁾ 005 -075.088 2.51 Cogan et al. (3) ⁽⁵¹⁾ 007 -106.120 1.37 Pincelli et al. (3) ⁽⁵¹⁾ 007 -064.101 2.05 Porcelli et al. (3) ⁽⁵¹⁾ 016 -064.097 2.73 Wylie et al. (1) ⁽⁵⁷⁾ 012 -067.109 2.87 Thompson et al. (59) 012 -067.109 2.63 Wylie et al. (4) ⁽⁴⁶⁾ 022 -044.091 2.63 Wylie et al. (50) 022 -044.095 3.63 Thompson et al. (59) 022 -047.092 3.63 Wyle et al. (1) ⁽⁵⁷⁾ 023 -051.097 3.17 Wyle et al. (2) ⁽⁴²⁾ 030 -069.128 1.80 Kokkinoplitis and chester ⁽⁴⁷⁾ 031 -066.131 2.22 Corr et al. (2) ⁽⁴⁶⁾ 041 -047.130 2.23 Corr et a	Coggan <i>et al.</i> (1) ⁽⁴³⁾	-0.11	-0.91, 0.69	2.73
Fullor dt at $(2)^{(45)}$ -007 -105, 091 182 Wylie et al. $(2)^{(47)}$ -004 -092, 083 228 Buck et al. $(1)^{(41)}$ -003 -053, 048 684 Wylie et al. $(3)^{(57)}$ -002 -083, 086 228 Vasconcellos et al. (55) -001 -079, 078 285 Balley et al. $(1)^{(60)}$ 003 -101, 108 160 Murphy et al. $(3)^{(51)}$ 005 -0-75, 085 2.74 Porcelli et al. $(3)^{(51)}$ 007 -106, 120 137 Rienks et al. $(2)^{(51)}$ 012 -043, 011 205 Coggan et al. $(4)^{(40)}$ 016 -074, 079 2.73 Wylie et al. $(3)^{(51)}$ 017 -106, 120 137 Thompson et al. (53) 022 -047, 092 363 Thompson et al. (53) 022 -047, 092 362 Christensen et al. $(2)^{(42)}$ 031 -075, 136 158 Porcelli et al. $(1)^{(51)}$ 031 -068, 129 180 Vijle et al. $(1)^{(51)}$ 031 -075, 136 220 Vylie et al. $(1)^{(51)}$ 031 -075, 136 200 Aucouturier et al. $(2)^{(38)}$ 043 -041, 137 179 Wylie et al. $(1)^{(51)}$ 031 -	Coggan <i>et al.</i> (2) ⁽⁴³⁾	-0.08	-0.88, 0.72	2.73
$\begin{array}{c c c c c c c c c c c c c c c c c c c $		-0.07	-1.05 0.91	1.82
This or ban, [41] -0.03 -0.53, 0.48 6.84 Wylie et al. (3) ⁽⁵⁷⁾ -0.03 -0.53, 0.48 6.84 Wylie et al. (3) ⁽¹⁵⁾ -0.01 -0.79, 0.78 2.85 Bailey et al. (1) ⁽¹⁶⁾ 0.03 -1.01, 1.08 1.60 Murphy et al. (40) 0.05 -0.75, 0.85 2.74 Porcelli et al. (3) ⁽¹⁵⁾ 0.07 -1.06, 1.20 1.37 Porcelli et al. (3) ⁽¹⁵⁾ 0.07 -1.06, 1.20 1.37 Porcelli et al. (3) ⁽¹⁵⁾ 0.12 -0.33, 1.17 1.59 Coggan et al. (4) ⁽⁴³⁾ 0.12 -0.23, 1.17 1.59 Coggan et al. (4) ⁽⁴³⁾ 0.12 -0.23, 1.17 1.59 Coggan et al. (5) 0.22 -0.47, 0.92 3.63 Thompson et al. ⁽⁵³⁾ 0.22 -0.47, 0.92 3.63 Thompson et al. (2) ⁽⁴²⁾ 0.31 -0.75, 1.36 3.62 Kokinopilis and chester ⁽⁴⁷⁾ 0.31 -0.75, 1.36 3.62 Vylie et al. (1) ⁽¹⁵⁾ 0.31 -0.68, 1.29 1.80 Kokinopilis and chester ⁽⁴⁷⁾ 0.31 -0.68, 1.29 1.80 Kokinopilis a	Wylie et al. (2) ⁽⁵⁷⁾	-0.04	-0.92 0.83	2.28
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	Buck et al. (41)	_0.03	-0.53 0.48	6.84
$ \begin{array}{c} \text{Triangle trains (0)} & \text{Triangle trains (0)} & \text{Triangle trains (1)} \\ \text{Wasconcellos et al. (55)} & \text{Triangle trains (1)} \\ \text{Bailey et al. (1)} & \text{Outs} - 0.79, 0.78, 0.78 & 2.85 \\ \text{Saling et al. (3)} & \text{Outs} - 0.79, 0.78, 0.78 & 2.55 \\ \text{Coggan et al. (3)} & \text{Outs} - 0.75, 0.88 & 2.51 \\ \text{Coggan et al. (3)} & \text{Outs} - 0.75, 0.88 & 2.51 \\ \text{Coggan et al. (3)} & \text{Outs} - 0.75, 0.88 & 2.51 \\ \text{Coggan et al. (3)} & \text{Outs} - 0.75, 0.88 & 2.51 \\ \text{Coggan et al. (3)} & \text{Outs} - 0.76, 0.98, 1.20 & 1.37 \\ \text{Porcelli et al. (2)} & \text{Outs} - 0.98, 1.01 & 2.05 \\ \text{Corgan et al. (4)} & \text{Outs} - 0.64, 0.97 & 2.73 \\ \text{Wylic et al. (1)} & \text{Outs} - 0.64, 0.97 & 2.73 \\ \text{Wylic et al. (1)} & \text{Outs} - 0.67, 1.09 & 2.27 \\ \text{Thompson et al.} & \text{Outs} - 0.51, 0.97 & 3.17 \\ \text{Thompson et al.} & \text{Outs} - 0.51, 0.97 & 3.17 \\ \text{Thompson et al.} & \text{Outs} - 0.51, 0.97 & 3.17 \\ \text{Nyakayiru et al.} & \text{Outs} - 0.75, 1.38 & 1.58 \\ \text{Porcelli et al. (3)} & \text{Outs} - 0.75, 1.38 & 1.58 \\ \text{Fulford et al. (3)} & \text{Outs} - 0.75, 1.38 & 1.58 \\ \text{Fulford et al. (3)} & \text{Outs} - 0.75, 1.38 & 1.58 \\ \text{Fulford et al. (3)} & \text{Outs} - 0.75, 1.38 & 1.58 \\ \text{Porcelli et al. (1)} & \text{Outs} - 0.75, 1.38 & 1.58 \\ \text{Fulford et al. (3)} & \text{Outs} - 0.75, 1.38 & 1.58 \\ \text{Fulford et al. (3)} & \text{Outs} - 0.75, 1.38 & 2.00 \\ \text{Aucouturier et al. (1)} & \text{Outs} - 0.32, 1.28 & 2.66 \\ \text{Aucouturier et al. (1)} & \text{Outs} - 0.32, 1.28 & 2.66 \\ \text{Kelly et al. (4)} & \text{Outs} - 0.38, 1.40 & 2.20 \\ \text{Outs et al. (2)} & \text{Outs} - 0.4, 1.44 & 1.98 \\ \text{Wylie et al. (2)} & \text{Outs} - 0.4, 1.44 & 1.97 \\ \text{Outs} - 0.53, -0.41, 1.48 & 1.97 \\ \text{Outs} - 0.53, -0.41, 1.48 & 1.97 \\ \text{Outs} - 0.54, -0.36, 1.43 & 2.19 \\ \text{Bailey et al. (2)} & \text{Outs} - 0.41, 1.48 & 1.97 \\ \text{Outs} - 0.58, -0.49, 1.66 & 1.52 \\ \text{Bailey et al. (2)} & \text{Outs} - 0.58, -0.49, 1.166 & 1.52 \\ \text{Bailey et al. (1)} & \text{Outs} - 0.58, -0.49, 1.166 & 1.52 \\ Bailey e$	While et al. (3) ⁽⁵⁷⁾	_0.02	-0.89 0.86	2.28
Vascuticities et al. (1) ⁽⁶⁸⁾ Murphy et al. (3) ⁽⁴³⁾ Porcelli et al. (3) ⁽⁴³⁾ Porcelli et al. (3) ⁽⁴³⁾ Porcelli et al. (3) ⁽⁵¹⁾ Porcelli et al. (2) ⁽⁵¹⁾ Coggan et al. (4) ⁽⁴⁴⁾ Porcelli et al. (2) ⁽⁵¹⁾ Coggan et al. (4) ⁽⁴⁴⁾ Coggan et al. (4) ⁽⁴²⁾ Christensen et al. (2) ⁽⁴²⁾ Christensen et al. (2) ⁽⁴²⁾ Christensen et al. (2) ⁽⁴²⁾ Cory et al. (4) ⁽⁴⁴⁾ Cogan et al. (1) ⁽⁵¹⁾ Christensen et al. (2) ⁽⁴²⁾ Cory et al. (4) ⁽⁴⁴⁾ Cogan et al. (3) ⁽⁴⁵⁾ Cogan et al. (3) ⁽⁴⁵⁾ Christensen et al. (2) ⁽⁴²⁾ Christensen et al. (2) ⁽⁴²⁾ Christensen et al. (2) ⁽⁴²⁾ Cory et al. (4) ⁽⁴⁴⁾ Cogan et al. (3) ⁽⁴⁵⁾ Cory et al. (4) ⁽⁴⁴⁾ Cogan et al. (2) ⁽⁴²⁾ Cory et al. (4) ⁽⁴⁴⁾ Cogan et al. (3) ⁽⁴⁵⁾ Cory et al. (4) ⁽⁴⁴⁾ Cogan et al. (3) ⁽⁴⁵⁾ Cory et al. (4) ⁽⁴⁶⁾ Cogan et al. (3) ⁽⁴⁷⁾ Cory et al. (4) ⁽⁴⁶⁾ Cogan et al. (3) ⁽¹⁷⁾ Cory et al. (4) ⁽⁴⁶⁾ Cogan et al. (3) ⁽¹⁷⁾ Cory et al. (4) ⁽⁴⁶⁾ Cosa Cory et a	Vasconcellos et al. ⁽⁵⁵⁾	0.01	0.70 0.78	2.85
Data by et al. (1) Murphy et al. (3) Coggan et al. (4) Coggan et al. (2) Forcelli et al. (2) Coggan et al. (4) Coggan et al. (4) Cogan et al. (4) Coggan et al. (4) Coggan et al. (4) Coggan et	Bailov at al (1) ⁽³⁹⁾	-0.03	1.01 1.09	1.60
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	Murphy at al ⁽⁴⁹⁾	0.05	0.70, 0.99	0.51
Codgan <i>et al.</i> (3) ⁽⁵¹⁾ Porcelli <i>et al.</i> (3) ⁽⁵¹⁾ Coggan <i>et al.</i> (4) ⁽⁴³⁾ Coggan <i>et al.</i> (1) ⁽⁵⁷⁾ Coll 1 - 0-67, 109 227 Thompson <i>et al.</i> (5 ⁽⁵⁾) Coll 2 - 0-47, 109 227 Thompson <i>et al.</i> (5 ⁽⁵⁾) Coll 2 - 0-47, 109 237 Thompson <i>et al.</i> (5 ⁽⁶⁾) Coll 2 - 0-47, 109 237 Thompson <i>et al.</i> (5 ⁽⁶⁾) Coll 2 - 0-47, 109 237 Thompson <i>et al.</i> (5 ⁽⁶⁾) Coll 2 - 0-47, 109 247 Coll 2 - 0-48, 0-91 3.63 Coll 2 - 0-44, 0-95 3.62 Christensen <i>et al.</i> (2) ⁽⁴²⁾ Coll 2 - 0-48, 129 1.80 Coll 2 - 0-48, 131 2.22 Larsen <i>et al.</i> (1) ⁽⁵¹⁾ Coll 2 - 0-48, 131 2.22 Larsen <i>et al.</i> (1) ⁽⁶¹⁾ Coll 2 - 0-48, 131 2.22 Larsen <i>et al.</i> (1) ⁽⁶¹⁾ Coll 2 - 0-48, 152 1.76 Breese <i>et al.</i> (40) Coll 2 - 0-48, 152 1.76 Breese <i>et al.</i> (40) Coll 2 - 0-48, 152 1.76 Coll 2 - 0-48, 152 1.77 Coll 2 - 0-48, 165 1.52 Coll 2 - 0-48, 152 1.77 Coll 2 - 0-48, 165 1.52 Coll 2 - 0-48, 152 1.77 Coll 2 - 0-48, 165 1.52 Coll 2 - 0-48, 152 1.77 Coll 2 - 0-4	Concern at al. (0) ⁽⁴³⁾	0.05	-0.79, 0.88	2.31
Porcelli et al. $(3)^{(4)}$ Porcelli et al. $(2)^{(51)}$ Coggan et al. $(4)^{(43)}$ Wylie et al. $(1)^{(57)}$ Thompson et al. (53) Thompson et al. (53) Wylie et al. (56) Wylie et al. (56) Cogram et al. (56) Wylie et al. (56) Wylie et al. (56) Correcting et al. (56) Fulford et al. $(2)^{(42)}$ Correcting et al. $(1)^{(57)}$ Fulford et al. $(3)^{(45)}$ Correcting et al. $(1)^{(57)}$ Correcting et al. $(2)^{(42)}$ Correcting et al. $(3)^{(45)}$ Correcting et al. $(1)^{(57)}$ Correcting et al. $(3)^{(45)}$ Correcting et al. $(3)^{(46)}$ Correcting et al. $(3)^{(46)}$ Correcting et al. $(3)^{(46)}$ Correcting et al. $(3)^{(46)}$ Correcting et al. $(2)^{(17)}$ Correcting et al.		0.05	-0.75, 0.85	2.74
Henks <i>et al.</i> $^{(4)}$ 0.09 -0-94, 1.01 2.05 Coggan <i>et al.</i> $^{(4)}$ 0.12 -0-93, 1.17 1.59 Coggan <i>et al.</i> $^{(5)}$ 0.21 -0-67, 1.09 2.27 Thompson <i>et al.</i> $^{(5)}$ 0.22 -0-48, 0.91 3.63 Thompson <i>et al.</i> $^{(5)}$ 0.22 -0-47, 0.92 3.63 Wylie <i>et al.</i> $^{(5)}$ 0.23 -0.51, 0.97 3.17 Nyakayiru <i>et al.</i> $^{(5)}$ 0.23 -0.51, 0.97 3.17 Nyakayiru <i>et al.</i> $^{(5)}$ 0.23 -0.51, 0.97 3.17 Nyakayiru <i>et al.</i> $^{(5)}$ 0.30 -0.69, 1.28 1.80 Kokkinopilitis and chester ⁽⁴⁷⁾ 0.31 -0.75, 1.36 1.58 Porcelli <i>et al.</i> $^{(1)^{(1)}}$ 0.31 -0.68, 1.29 1.80 Fulford <i>et al.</i> $^{(3)^{(5)}}$ 0.38 -0.61, 1.37 1.79 Wylie <i>et al.</i> $^{(1)^{(5)}}$ 0.43 -0.64, 0.91 2.23 Corry <i>et al.</i> $^{(4)}$ 0.43 -0.64, 0.91 2.23 Corry <i>et al.</i> $^{(4)}$ 0.43 -0.64, 1.31 2.22 Larsen <i>et al.</i> $^{(15)}$ 0.43 -0.51, 1.36 2.00 Aucouturier <i>et al.</i> $^{(1)^{(30)}}$ 0.45 -0.38, 1.40 2.20 Mosher <i>et al.</i> $^{(1)^{(30)}}$ 0.51 -0.38, 1.40 2.20 Mosher <i>et al.</i> $^{(10)}$ 0.52 -0.44, 1.44 1.98 Wylie <i>et al.</i> $^{(2)^{(2)}}$ 0.54 -0.36, 1.43 2.19 Bailey <i>et al.</i> $^{(2)^{(2)}}$ 0.54 -0.36, 1.43 2.19 Bailey <i>et al.</i> $^{(2)^{(2)}}$ 0.55 -0.41, 1.48 1.97 Wylie <i>et al.</i> $^{(1)^{(40)}}$ 0.55 -0.49, 1.65 1.52 Bailey <i>et al.</i> $^{(1)^{(40)}}$ 0.56 -0.29, 1.62 1.52 Bailey <i>et al.</i> $^{(1)^{(40)}}$ 0.56 -0.49, 1.65 1.52 Bailey <i>et al.</i> $^{(1)^{(40)}}$ 0.56 -0.49, 1.65 1.52 Bailey <i>et al.</i> $^{(1)^{(40)}}$ 0.56 -0.49, 1.65 1.52 Bailey <i>et al.</i> $^{(2)^{(40)}}$ 0.56 -0.29, 1.62 1.52 Bailey <i>et al.</i> $^{(1)^{(40)}}$ 0.56 -0.29, 1.62 1.93 Kelly <i>et al.</i> $^{(1)^{(40)}}$ 0.66 -0.29	Porcelli et al. (3)	0.07	-1.06, 1.20	1.37
Porcelli et al. $(2)^{(4)}$ Coggan et al. $(4)^{(43)}$ Wylie et al. $(1)^{(57)}$ Thompson et al. (35) Thompson et al. (56) Wylie et al. (56) Wylie et al. (56) Christensen et al. $(2)^{(42)}$ Christensen et al. $(2)^{(43)}$ Christensen et al. $(2)^{(43)}$ Christensen et al. $(2)^{(43)}$ Christensen et al. $(2)^{(43)}$ Christensen et al. $(2)^{(38)}$ Aucouturier et al. $(1)^{(38)}$ Christensen et al. $(2)^{(38)}$ Christensen et al. $(2)^{(38)}$ Christensen et al. $(2)^{(38)}$ Christensen et al. $(2)^{(38)}$ Christensen et al. $(2)^{(39)}$ Bailey et al. $(2)^{(17)}$ Wylie et al. $(2)^{(17)}$ Bailey et al. $(2)^{(17)}$ Christensen et al. $(2)^{(39)}$ Christensen et al. $(2)^{(46)}$ Christensen et al. $(2)^{(46)}$ Christ		0.09	-0.84, 1.01	2.05
Coggan et al. $(4)^{(157)}$ Wylie et al. $(1)^{(57)}$ Thompson et al. (53) Thompson et al. (54) Ocean et al. (56) Cogan et al. $(2)^{(42)}$ Christensen et al. $(2)^{(42)}$ Christensen et al. $(2)^{(42)}$ Christensen et al. $(2)^{(42)}$ Correctile et al. $(1)^{(51)}$ Fulford et al. $(3)^{(45)}$ Wylie et al. $(1)^{(51)}$ Correctile et al. $(1)^{(51)}$ Correctile et al. $(1)^{(51)}$ Correctile et al. $(1)^{(51)}$ Correctile et al. $(1)^{(51)}$ Wylie et al. $(1)^{(17)}$ Wylie et al. $(1)^{(38)}$ Kelly et al. $(4)^{(46)}$ Bailey et al. $(2)^{(38)}$ Halley et al. $(2)^{(38)}$ Halley et al. $(2)^{(38)}$ Halley et al. $(2)^{(39)}$ Bailey et al. $(2)^{(39)}$ Bailey et al. $(2)^{(39)}$ Bailey et al. $(2)^{(39)}$ Halley et al. $(2)^{(39)}$ Bailey et al. $(2)^{(39)}$ Correctile et al. $(2)^{(39)}$ Correctile et al. $(2)^{(46)}$ Correctile	Porcelli et al. (2) ⁽⁰¹⁾	0.12	-0.93, 1.17	1.59
Wylie et al. (1) ⁽¹⁷⁾ 0.21 $-0.67, 1.09$ 227 Thompson et al. ⁽⁵³⁾ 0.22 $-0.48, 0.91$ 3.63 Thompson et al. ⁽⁵⁴⁾ 0.22 $-0.47, 0.92$ 3.63 Wylie et al. ⁽⁵⁶⁾ 0.23 $-0.51, 0.97$ 3.17 Nyakayiru et al. ⁽⁵⁰⁾ 0.23 $-0.69, 1.28$ 1.80 Kokkinoplitis and chester ⁽⁴⁷⁾ 0.31 $-0.75, 1.36$ 1.58 Porcelli et al. (1) ⁽⁶¹⁾ 0.31 $-0.75, 1.36$ 1.58 Fulford et al. (2) ⁽⁴²⁾ 0.34 $-0.75, 1.36$ 1.58 Corry et al. ⁽⁴⁴⁾ 0.31 $-0.75, 1.36$ 2.23 Larsen et al. (1) ⁽¹⁷⁾ 0.41 $-0.47, 1.30$ 2.23 Corry et al. ⁽⁴⁴⁾ 0.43 $-0.51, 1.36$ 2.00 Aucouturier et al. (1) ⁽¹⁸⁾ 0.43 $-0.51, 1.36$ 2.00 Aucouturier et al. (1) ⁽¹⁸⁾ 0.45 $-0.36, 1.26$ 2.66 Kelly et al. (3) ⁽¹⁷⁾ 0.51 $-0.38, 1.40$ 2.20 Mosher et al. (2) ⁽¹³⁾ 0.52 $-0.44, 1.52$ 1.76 Bailey et al. (2) ⁽¹⁷⁾ 0.54 $-0.36, 1.43$ 2.19	Coggan <i>et al.</i> (4) ⁽⁺⁵⁾	0.16	<i>–</i> 0·64, 0·97	2.73
Thompson <i>et al.</i> ⁽⁵⁶⁾ Thompson <i>et al.</i> ⁽⁵⁶⁾ Wylie <i>et al.</i> ⁽⁵⁶⁾ Nyakayin <i>et al.</i> ⁽⁵⁰⁾ Christensen <i>et al.</i> (2) ⁽⁴²⁾ Christensen <i>et al.</i> (2) ⁽⁴²⁾ Christensen <i>et al.</i> (2) ⁽⁴²⁾ Christensen <i>et al.</i> (2) ⁽⁴²⁾ Christensen <i>et al.</i> (1) ⁽⁵¹⁾ Porcelli <i>et al.</i> (1) ⁽⁵¹⁾ Putford <i>et al.</i> (3) ⁽⁴⁶⁾ Christensen <i>et al.</i> (1) ⁽⁵¹⁾ Christensen <i>et al.</i> (1) ⁽¹⁷⁾ Wylie <i>et al.</i> (1) ⁽¹⁷⁾ Christensen <i>et al.</i> (2) ⁽³⁸⁾ Aucouturier <i>et al.</i> (2) ⁽³⁸⁾ Mylie <i>et al.</i> (3) ⁽⁴⁶⁾ Christensen <i>et al.</i> (2) ⁽³⁸⁾ Mylie <i>et al.</i> (3) ⁽⁴⁶⁾ Christensen <i>et al.</i> (2) ⁽³⁹⁾ Bailey <i>et al.</i> (2) ⁽³⁹⁾ Bailey <i>et al.</i> (2) ⁽³⁹⁾ Christensen <i>et al.</i> (2) ⁽⁴⁶⁾ Christensen <i>et al.</i> (3) ⁽⁴⁶⁾ Christensen <i>et al.</i> (3) ⁽⁴⁶⁾	Wylie et al. (1) ⁽³⁷⁾	0.21	–0·67, 1·09	2.27
Thompson et al. $^{(56)}$ Wylie et al. $^{(56)}$ Nyakayiru et al. $^{(56)}$ Christensen et al. $(2)^{(42)}$ Kokkinoplitis and chester ⁽⁴⁷⁾ Pulford et al. $(3)^{(45)}$ Wylie et al. $(3)^{(45)}$ Wylie et al. $(1)^{(17)}$ Curry et al. $^{(44)}$ Aucouturier et al. $(1)^{(36)}$ Kelly et al. $(3)^{(45)}$ Wylie et al. $(2)^{(38)}$ Bailey et al. $(2)^{(39)}$ Bailey et al. $(2)^{(42)}$ Kelly et al. $(2)^{(42)}$ Corry et al. (40) Corry et al. $(2)^{(17)}$ Corry et al. $(2)^{(17)}$ Corry et al. $(2)^{(17)}$ Corry et al. $(2)^{(17)}$ Corry et al. $(2)^{(46)}$ Corry et al. $(2)^{(46)$	Thompson et al. ⁽⁵³⁾	0.22	–0·48, 0·91	3.63
Wylie et al. $^{(56)}$ 0-23 -0-51, 0-97 3-17 Nyakayiru et al. $^{(50)}$ 0-26 -0-44, 0-95 3-62 Christensen et al. $(2)^{(42)}$ 0-30 -0-69, 1-28 1-80 Kokkinoplitis and chester ⁽⁴⁷⁾ 0-31 -0-68, 1-29 1-80 Porcelli et al. $(1)^{(51)}$ 0-31 -0-68, 1-29 1-80 Fulford et al. $(3)^{(45)}$ 0-38 -0-61, 1-37 1-79 Wylie et al. $(1)^{(17)}$ 0-41 -0-47, 1-30 2-23 Corry et al. $^{(44)}$ 0-43 -0-66, 1-21 2-20 Aucouturier et al. $(2)^{(38)}$ 0-45 -0-36, 1-26 2-66 Aucouturier et al. $(1)^{(30)}$ 0-50 -0-32, 1-31 2-65 Kelly et al. $(4)^{(46)}$ 0-52 -0-30, 1-33 2-64 Bailey et al. $(2)^{(17)}$ 0-53 -0-41, 1-48 1-97 Wylie et al. $(2)^{(17)}$ 0-58 -0-49, 1-65 1-52 Bailey et al. $(2)^{(46)}$ 0-52 -0-33, 1-57 1-52 Bailey et al. $(2)^{(46)}$ 0-52 -0-33, 1-57 1-52 Bailey et al. $(2)^{(46)}$ 0-52 -0-33, 1-57	Thompson et al. ⁽⁵⁴⁾	0.22	–0·47, 0·92	3.63
Nyakayiru et al. $^{(50)}$ 0-26 -0-44, 0-95 3-62 Christensen et al. $(2)^{(42)}$ 0-30 -0-69, 1-28 1-80 Kokkinoplitis and chester ⁽⁴⁷⁾ 0-31 -0-75, 1-36 1-58 Porcelli et al. $(1)^{(51)}$ 0-31 -0-68, 1-29 1-80 Fulford et al. $(3)^{(45)}$ 0-38 -0-61, 1-37 1-79 Wylie et al. $(1)^{(17)}$ 0-41 -0-47, 1-30 2-23 Corry et al. $^{(14)}$ 0-43 -0-51, 1-36 2-00 Aucouturier et al. $(2)^{(38)}$ 0-43 -0-51, 1-36 2-00 Aucouturier et al. $(1)^{(38)}$ 0-45 -0-38, 1-26 2-66 Aucouturier et al. $(3)^{(17)}$ 0-50 -0-32, 1-31 2-65 Kelly et al. $(4)^{(46)}$ 0-52 -0-30, 1-33 2-64 Bailey et al. $(2)^{(17)}$ 0-54 -0-36, 1-43 2-176 Bailey et al. $(2)^{(17)}$ 0-58 -0-49, 1-65 1-52 Bailey et al. $(2)^{(46)}$ 0-52 -0-33, 1-57 1-52 Bailey et al. $(2)^{(46)}$ 0-54 -0-33, 1-57 1-52 Bailey et al. $(2)^{(46)}$ 0-54 -0-33, 1-	Wylie et al. ⁽⁵⁶⁾	0.53	–0·51, 0·97	3.17
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	Nyakayiru et al. ⁽⁵⁰⁾	0.56	–0·44, 0·95	3.62
Kokkinoplitis and chester ⁽⁴⁷⁾ 0.31 -0.75 , 1.36 1.58 Porcelli et al. (1) ⁽⁵¹⁾ 0.31 -0.68 , 1.29 1.80 Fulford et al. (3) ⁽⁴⁵⁾ 0.34 -0.68 , 1.29 1.80 Wylie et al. (1) ⁽¹⁷⁾ 0.41 -0.47 , 1.30 2.23 Corry et al. ⁽⁴⁴⁾ 0.43 -0.61 , 1.37 1.79 Mylie et al. (2) ⁽³⁸⁾ 0.43 -0.61 , 1.37 2.23 Larsen et al. ⁽¹⁵⁾ 0.43 -0.61 , 1.37 2.23 Mucouturier et al. (1) ⁽³⁸⁾ 0.43 -0.61 , 1.37 2.22 Aucouturier et al. (1) ⁽³⁸⁾ 0.43 -0.61 , 1.37 2.22 Mylie et al. (3) ⁽¹⁷⁾ 0.41 -0.44 1.98 Wylie et al. (2) ⁽¹⁷⁾ 0.51 -0.38 , 1.40 2.20 Mosher et al. ⁽⁴⁰⁾ 0.52 -0.30 , 1.33 2.64 Bailey et al. (2) ⁽¹⁷⁾ 0.54 -0.36 , 1.43 2.19 Bailey et al. (2) ⁽⁴⁶⁾ 0.59 -0.49 , 1.65 1.52 Bailey et al. (2) ⁽⁴⁶⁾ 0.64 -0.31 , 1.59 1.94 Lansley et al. (2) ⁽⁴⁶⁾ 0.66	Christensen et al. (2) ⁽⁴²⁾	0.30	–0·69, 1·28	1.80
Porcelli et al. (1) ⁽⁵¹⁾ 0.31 $-0.68, 1.29$ 1.80 Fulford et al. (3) ⁽⁴⁵⁾ 0.38 $-0.61, 1.37$ 1.79 Wylie et al. (1) ⁽¹⁷⁾ 0.41 $-0.47, 1.30$ 2.23 Corry et al. ⁽⁴⁴⁾ 0.43 $-0.46, 1.31$ 2.22 Larsen et al. ⁽¹⁵⁾ 0.43 $-0.66, 1.26$ 2.66 Aucouturier et al. (2) ⁽³⁸⁾ 0.45 $-0.36, 1.26$ 2.66 Aucouturier et al. (1) ⁽⁴⁶⁾ 0.50 $-0.32, 1.31$ 2.65 Kelly et al. (4) ⁽⁴⁶⁾ 0.52 $-0.38, 1.40$ 2.20 Mosher et al. ⁽⁴⁸⁾ 0.52 $-0.38, 1.40$ 2.20 Mosher et al. ⁽⁴⁰⁾ 0.52 $-0.38, 1.40$ 2.20 Mosher et al. ⁽⁴⁰⁾ 0.52 $-0.38, 1.40$ 2.20 Mosher et al. ⁽⁴¹⁾ 0.52 $-0.38, 1.43$ 2.10 Bailey et al. (2) ⁽¹⁷⁾ 0.53 $-0.41, 1.48$ 1.97 Wylie et al. (2) ⁽¹⁷⁾ 0.54 $-0.36, 1.43$ 2.19 Bailey et al. (2) ⁽⁴⁶⁾ 0.52 $-0.49, 1.65$ 1.52 Bailey et al. (2) ⁽⁴⁶⁾ 0.64 $-0.31, 1.59$ 1.94	Kokkinoplitis and chester ⁽⁴⁷⁾	0.31	–0·75, 1·36	1.58
Fulford et al. $(3)^{(45)}$ 0.38 -0-61, 1:37 1.79 Wylie et al. $(1)^{(17)}$ 0.41 -0.47, 1:30 2.23 Corry et al. $^{(44)}$ 0.43 -0.46, 1:31 2.22 Larsen et al. $^{(15)}$ 0.43 -0.46, 1:31 2.22 Aucouturier et al. $(2)^{(38)}$ 0.43 -0.51, 1:36 2:00 Aucouturier et al. $(1)^{(38)}$ 0.43 -0.51, 1:36 2:00 Mucouturier et al. $(3)^{(17)}$ 0.50 -0.32, 1:31 2:65 Kelly et al. $(4)^{(46)}$ 0.52 -0.30, 1:33 2:64 Bailey et al. $(3)^{(17)}$ 0.52 -0.44, 1:44 1:98 Wylie et al. $(2)^{(17)}$ 0.52 -0.34, 1:40 2:20 Mosher et al. $(2)^{(17)}$ 0.53 -0.41, 1:48 1:97 Wylie et al. $(2)^{(17)}$ 0.58 -0.49, 1:65 1:52 Bailey et al. $(2)^{(39)}$ 0.58 -0.49, 1:65 1:52 Bailey et al. $(2)^{(46)}$ 0.62 -0.33, 1:57 1:95 Kelly et al. $(2)^{(46)}$ 0.64 -0.31, 1:59 1:94 Lansley et al. $(1)^{(46)}$ 0.66 -0.29, 1:62	Porcelli et al. (1) ⁽⁵¹⁾	0.31	-0·68, 1·29	1.80
Wylie et al. (1) 0.41 -0.47 , 1:30 2.23 Corry et al. (44) 0.43 -0.47 , 1:30 2.23 Larsen et al. (15) 0.43 -0.46 , 1:31 2:22 Aucouturier et al. (2) 0.43 -0.46 , 1:31 2:22 Aucouturier et al. (13) 0.43 -0.46 , 1:31 2:22 Aucouturier et al. (13) 0.43 -0.46 , 1:31 2:22 Aucouturier et al. (13) 0.43 -0.46 , 1:31 2:22 Muscularier et al. (13) 0.43 -0.41 , 1:44 1:98 Wylie et al. (3) 0.50 -0.44 , 1:44 1:98 Wylie et al. (3) 0.51 -0.38 , 1:40 2:20 Mosher et al. (40) 0.52 -0.30 , 1:33 2:64 Bailey et al. (2) 0.52 -0.41 , 1:48 1:97 Wylie et al. (2) 0.52 -0.41 , 1:48 1:97 Wylie et al. (2) 0.53 -0.41 , 1:48 1:97 Wylie et al. (2) 0.58 -0.49 , 1:65 1:52 Bailey et al. (2) 0.58 -0.49 , 1:65 1:52 Kelly et al. (2) 0.64	Fulford et al. (3) ⁽⁴⁵⁾	0.38	-0.61, 1.37	1.79
Corry et al. $^{(44)}$ 0-43 -0-46, 1.31 2:22 Larsen et al. $^{(15)}$ 0-43 -0-51, 1:36 2:00 Aucouturier et al. (1) ⁽³⁸⁾ 0-45 -0-36, 1:26 2:66 Aucouturier et al. (1) ⁽³⁸⁾ 0-50 -0-32, 1:31 2:65 Kelly et al. (4) ⁽⁴⁶⁾ 0:50 -0-32, 1:31 2:65 Wylie et al. (3) ⁽¹⁷⁾ 0:51 -0:38, 1:40 2:20 Mosher et al. ⁽⁴⁶⁾ 0:52 -0:30, 1:33 2:64 Bailey et al. (2) ⁽¹⁷⁾ 0:51 -0:38, 1:52 1:76 Breese et al. ⁽⁴⁰⁾ 0:52 -0:41, 1:48 1:97 Wylie et al. (2) ⁽¹⁷⁾ 0:54 -0:66, 1:43 2:19 Bailey et al. (2) ⁽¹⁹⁾ 0:58 -0:49, 1:65 1:52 Bailey et al. (2) ⁽⁴⁶⁾ 0:62 -0:33, 1:57 1:95 Kelly et al. (2) ⁽⁴⁶⁾ 0:64 -0:31, 1:59 1:94 Lansley et al. (1) ⁽⁴⁶⁾ 0:66 -0:29, 1:62 1:93 Kelly et al. (1) ⁽⁴⁶⁾ 0:66 0:25 1:77 Overall (t^2 =0:0%, P=1:000) 0:25 0:12, 0:38 100:00	Wylie et al. (1) ⁽¹⁷⁾	0.41	-0.47, 1.30	2.23
Larsen <i>et al.</i> ⁽¹⁵⁾ Aucouturier <i>et al.</i> (2) ⁽³⁸⁾ Aucouturier <i>et al.</i> (1) ⁽³⁶⁾ Kelly <i>et al.</i> (4) ⁽⁴⁶⁾ Wylie <i>et al.</i> (4) ⁽⁴⁶⁾ Wylie <i>et al.</i> (4) ⁽⁴⁶⁾ Wylie <i>et al.</i> (4) ⁽⁴⁶⁾ Wylie <i>et al.</i> (4) ⁽⁴⁶⁾ Bailey <i>et al.</i> (4) ⁽⁴⁰⁾ Bailey <i>et al.</i> (4) ⁽⁴⁰⁾ Wylie <i>et al.</i> (2) ⁽¹⁷⁾ Breese <i>et al.</i> ⁽⁴⁰⁾ Wylie <i>et al.</i> (2) ⁽¹⁷⁾ Bailey <i>et al.</i> (2) ⁽¹⁷⁾ Bailey <i>et al.</i> (2) ⁽³⁹⁾ Bailey <i>et al.</i> (2) ⁽³⁹⁾ Bailey <i>et al.</i> (2) ⁽³⁹⁾ Bailey <i>et al.</i> (2) ⁽⁴⁶⁾ Kelly <i>et al.</i> (2) ⁽⁴⁶⁾ Kelly <i>et al.</i> (2) ⁽⁴⁶⁾ Kelly <i>et al.</i> (2) ⁽⁴⁶⁾ Correct (2) ⁽⁴⁶⁾ Co	Corry et al. (44)	0.43	-0.46, 1.31	2.22
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	Larsen et al. ⁽¹⁵⁾	0.43	-0.51, 1.36	2.00
Aucodulation of al. (1) ⁽³⁸⁾ 0:50 -0.32, 1:31 2:65 Kelly et al. (4) ⁽⁴⁶⁾ 0:50 -0.32, 1:31 2:65 Mosher et al. (1) ⁽¹⁷⁾ 0:51 -0.38, 1:40 2:20 Mosher et al. (1) ⁽⁴⁰⁾ 0:52 -0.30, 1:33 2:64 Bailey et al. (1) ⁽¹⁷⁾ 0:52 -0.34, 1:52 1:76 Breese et al. (40) 0:52 -0.44, 1:48 1:97 Wylie et al. (2) ⁽¹⁷⁾ 0:54 -0.36, 1:43 2:19 Bailey et al. (2) ⁽¹⁷⁾ 0:54 -0.36, 1:43 2:19 Bailey et al. (2) ⁽¹⁹⁾ 0:58 -0.49, 1:65 1:52 Bailey et al. (2) ⁽¹⁹⁾ 0:52 -0.33, 1:57 1:95 Kelly et al. (2) ⁽⁴⁶⁾ 0:62 -0.33, 1:57 1:95 Kelly et al. (2) ⁽⁴⁶⁾ 0:66 -0.29, 1:62 1:93 Kelly et al. (1) ⁽⁴⁶⁾ 0:66 -0.29, 1:62 1:93 Kelly et al. (1) ⁽⁴⁶⁾ 0:62 0:03, 1:59 1:94 Lansley et al. (1) ⁽⁴⁶⁾ 0:62 0:03, 1:00 Verail (l^2 =0:0%, P =1:000) 0:25 0:12, 0:38 100:00		0.45	-0.36 1.26	2.66
Padecidate of (1) 0.50 0.52, 101 1.00 Wylie et al. (3) ⁽¹⁷⁾ 0.51 -0.38, 1.40 2.20 Mosher et al. (48) 0.52 -0.30, 1.33 2.64 Bailey et al. (18) 0.52 -0.48, 1.52 1.76 Breese et al. (40) 0.53 -0.41, 1.48 1.97 Wylie et al. (2) ⁽¹⁷⁾ 0.54 -0.36, 1.43 2.19 Bailey et al. (2) ⁽¹⁷⁾ 0.54 -0.36, 1.43 2.19 Bailey et al. (2) ⁽¹⁹⁾ 0.58 -0.49, 1.66 1.52 Bailey et al. (2) ⁽⁴⁶⁾ 0.62 -0.33, 1.57 1.95 Kelly et al. (2) ⁽⁴⁶⁾ 0.64 -0.31, 1.59 1.94 Lansley et al. (1 ⁽⁴⁶⁾) 0.66 -0.29, 1.62 1.93 Kelly et al. (1) ⁽⁴⁶⁾ 0.66 -0.25 1.77 Overall (l^2 =0.0%, P=1.000) 0.25 0.12, 0.38 100-00		0.50	_0.32 1.31	2.65
$\begin{array}{c} \text{Herry of tal.} (4) \\ \text{Wylie et al.} (3)^{(17)} \\ \text{Wosher et al.} (46) \\ \text{Bailey et al.} (18) \\ \text{Bailey et al.} (2)^{(17)} \\ \text{Wylie et al.} (2)^{(17)} \\ \text{Bailey et al.} (2)^{(17)} \\ \text{Bailey et al.} (2)^{(17)} \\ \text{Bailey et al.} (2)^{(19)} \\ \text{Bailey et al.} (2)^{(39)} \\ \text{Bailey et al.} (2)^{(39)} \\ \text{Bailey et al.} (2)^{(46)} \\ \text{Comparison of tables et al.} (2)^{(46)} \\ Comparison of tables et al$	Kelly et al. (1) ⁽⁴⁶⁾	0.50	-0.44 1.44	1.98
Wyle et al. (10) $0.51 - 0.30, 140$ 2.40 Mosher et al. (48) $0.52 - 0.30, 143$ 2.64 Bailey et al. (18) $0.52 - 0.48, 1.52$ 1.76 Breese et al. (40) $0.53 - 0.41, 1.48$ 1.97 Wylie et al. (2) ⁽¹⁷⁾ $0.54 - 0.36, 1.43$ 2.19 Bailey et al. (2) ⁽³⁹⁾ $0.58 - 0.49, 1.65$ 1.52 Bailey et al. (2) ⁽⁴⁶⁾ $0.62 - 0.33, 1.57$ 1.95 Kelly et al. (2) ⁽⁴⁶⁾ $0.64 - 0.31, 1.59$ 1.94 Lansley et al. (1) ⁽⁴⁶⁾ $0.66 - 0.29, 1.62$ 1.93 Vorall ($l^2 = 0.0\%, P = 1.000$) $0.25 - 0.12, 0.38$ 100.00	While at al. (2) ⁽¹⁷⁾	0.51	_0.38 1.40	2.20
Most et al. 0.52 -0.63, 1.53 2.04 Bailey et al. 0.52 -0.48, 1.52 1.76 Breese et al. 0.53 -0.41, 1.48 1.97 Wylie et al. (2) ⁽³⁹⁾ 0.54 -0.36, 1.43 2.19 Bailey et al. (2) ⁽³⁹⁾ 0.58 -0.49, 1.65 1.52 Bailey et al. (3) ⁽⁴⁶⁾ 0.52 -0.33, 1.57 1.95 Kelly et al. (2) ⁽⁴⁶⁾ 0.64 -0.31, 1.59 1.94 Lansley et al. (1) ⁽⁴⁶⁾ 0.66 -0.29, 1.62 1.93 Kelly et al. (1) ⁽⁴⁶⁾ 0.62 0.12, 0.38 100.00	Mochar at al ⁽⁴⁸⁾	0.52	0.20 1.22	2.64
Date of al. 0.52 -0.40, 1.52 1.10 Breese et al. 0.53 -0.41, 1.48 1.97 Wylie et al. (2) ⁽³⁹⁾ 0.54 -0.36, 1.43 2.19 Bailey et al. (2) ⁽³⁹⁾ 0.58 -0.49, 1.65 1.52 Bailey et al. (2) ⁽⁴⁶⁾ 0.62 -0.33, 1.57 1.95 Kelly et al. (2) ⁽⁴⁶⁾ 0.64 -0.31, 1.59 1.94 Lansley et al. (1) ⁴⁶ 0.66 -0.29, 1.62 1.93 Kelly et al. (1) ⁴⁶ 0.66 -0.25 1.77 Overall (l ² =0.0%, P=1.000) 0.25 0.12, 0.38 100-00	Bailov at al. (18)	0.52	0.49 1.52	1.76
biteste et al. $0.53 - 0.41, 143$ 1.97 Wylie et al. (2) ⁽¹⁷⁾ $0.54 - 0.36, 1.43$ 2.19 Bailey et al. (2) ⁽³⁹⁾ $0.58 - 0.49, 1.65$ 1.52 Bailey et al. (3) ⁽⁴⁶⁾ $0.62 - 0.33, 1.57$ 1.95 Kelly et al. (2) ⁽⁴⁶⁾ $0.64 - 0.31, 1.59$ 1.94 Lansley et al. (1) ⁽⁴⁶⁾ $0.66 - 0.29, 1.62$ 1.93 Kelly et al. (1) ⁽⁴⁶⁾ $0.66 - 0.29, 1.62$ 1.93 Kelly et al. (1) ⁽⁴⁶⁾ $0.25 - 0.12, 0.38$ 100.00 -4.2 0.42 4.2	Broose et al.	0.52	0.41 1.49	1.07
Wylie brail (2) $0.54 - 0.30, 143$ 2.19 Bailey et al. (2) $0.58 - 0.49, 1.65$ 1.52 Bailey et al. (2) $0.59 - 0.49, 1.66$ 1.52 Kelly et al. (2) ⁽⁴⁶⁾ $0.62 - 0.33, 1.57$ 1.95 Kelly et al. (2) ⁽⁴⁶⁾ $0.66 - 0.29, 1.62$ 1.93 Kelly et al. (1) ⁽⁴⁶⁾ $0.66 - 0.29, 1.62$ 1.93 Kelly et al. (1) ⁽⁴⁶⁾ $0.25 - 0.12, 0.38$ 100.00 -4.2 0 4.2		0.53	0.26 1.42	0.10
Bailey et al. (2) $0.58 - 0.49$, 1.65 1.52 Bailey et al. (3) $0.59 - 0.49$, 1.66 1.52 Kelly et al. (2) $0.64 - 0.31$, 1.57 1.95 Lansley et al. (2) $0.66 - 0.29$, 1.62 1.93 Kelly et al. (1) $1.06 - 0.62$, 1.62 1.93 Kelly et al. (1) $1.06 - 0.62$, 1.62 1.93 Verall ($I^2 = 0.0\%$, $P = 1.000$) $0.25 - 0.12$, $0.38 - 100.00$		0.54	-0.36, 1.43	2.19
Bailey et al. (3) ⁽⁴⁶⁾ 0:59 -0:49, 1:66 1:52 Kelly et al. (3) ⁽⁴⁶⁾ 0:62 -0:33, 1:57 1:95 Lansley et al. (2) ⁽⁴⁶⁾ 0:66 -0:29, 1:62 1:93 Kelly et al. (1) ⁽⁴⁶⁾ 0:66 -0:29, 1:62 1:93 Overall (l ² =0:0%, P=1:000) 0:25 0:12, 0:38 100:00		0.58	-0.49, 1.65	1.52
Kelly et al. $(3)^{(-7)}$ 0.62 -0.33, 1.57 1.95 Kelly et al. $(2)^{(46)}$ 0.64 -0.31, 1.59 1.94 Lansley et al. $(2)^{(46)}$ 0.66 -0.29, 1.62 1.93 Kelly et al. $(1)^{(46)}$ 0.66 -0.29, 1.62 1.93 Overall $(l^2=0.0\%, P=1.000)$ 0.25 0.12, 0.38 100.00	Balley et al. (c)	0.59	-0.49, 1.66	1.92
Kelly et al. $(2)^{(N_f)}$ 0.64 -0.31, 1.59 1.94 Lansley et al. $(2)^{(N_f)}$ 0.66 -0.29, 1.62 1.93 Kelly et al. $(1)^{(46)}$ 1.06 0.06, 2.05 1.77 Overall $(l^2 = 0.0\%, P = 1.000)$ 0.25 0.12, 0.38 100-00	Kelly <i>et al.</i> (3) ⁽¹⁶⁾	0.62	-0.33, 1.57	1.95
Lansley et al. ⁽²³⁾ Kelly et al. (1) ⁽⁴⁶⁾ Overall (l ² =0.0%, P=1.000) -4.2 0 4.2 0 0.66 0.66 0.029, 1.62 1.93 1.06 0.06, 2.05 1.77 0.25 0.12, 0.38 100.00	Kelly et al. (2) ⁽⁴³⁾	0.64	-0.31, 1.59	1.94
Kelly et al. (1) ^(ro) $1 \cdot 06 0 \cdot 06, 2 \cdot 05 1 \cdot 77$ Overall ($I^2 = 0 \cdot 0\%, P = 1 \cdot 000$) $0 \cdot 25 0 \cdot 12, 0 \cdot 38 100 \cdot 00$ I I -4 \cdot 2 0	Lansley et al. (46)	0.66	–0·29, 1·62	1.93
Overall (/ ² = 0.0%, P = 1.000)	Kelly et al. (1) ⁽⁴⁰⁾	1.06	0.06, 2.05	1.77
	Overall ($I^{2} = 0.0\%, P = 1.000$)	0.25	0.12, 0.38	100.00
	1	1		
	 	4.2		

Fig. 3. Forest plot of physical performance following dietary NO3 supplementation in non-athletes. SMD, standardised mean difference.

analysis, heterogeneity was observed among these studies $(I^2 = 0\%; Q = 13.31, df = 16, P = 0.65).$

Study

Non-athletes subjected to long-duration tests. After pooling the data from twenty-five trials, the mean effect size was 0.33 (95% CI 0.15, 0.51), which indicates that the dietary NO₃ supplementation had a small and significant beneficial effect on physical performance (P < 0.05; Fig. 7). According to a fixedeffects analysis, no heterogeneity was observed among these studies $(I^2 = 0\%; Q = 8.01, df = 24, P = 0.99).$

Athletes subjected to long-duration tests. After pooling the data from forty-four trials, the mean effect size was 0.05 (95% CI -0.07, 0.17), which indicates that the dietary NO₃ supplementation had a negligible and non-significant effect on physical performance (P > 0.05; Fig. 8). According to a fixed-effects analysis, no heterogeneity was observed among these studies $(I^2=0\%; O=4.82, df=43, P=1.00)$. The subsequent analysis consisted of subdividing the non-athletes that performed longduration tests according to the test protocol used.

Non-athletes subjected to long-duration, open-ended tests. After pooling the data from fourteen trials, the mean effect size was 0.47 (95% CI 0.23, 0.71), which indicates that the dietary NO₃ supplementation had a small and significant beneficial effect on physical performance (P < 0.05; Fig. 9). According to a fixed-effects analysis, no heterogeneity was observed among these studies $(I^2 = 0\%; Q = 3.77, df = 13,$ P = 0.99).

Non-athletes subjected to long-duration time trials. After pooling the data from four trials, the mean effect size was 0.12 (95% CI - 0.37, 0.61), which indicates that the dietary NO₃ supplementation had a negligible and non-significant effect on physical performance (P > 0.05; Fig. 10). According to a fixedeffects analysis, no heterogeneity was observed among these studies $(I^2 = 0\%; Q = 0.16, df = 3, P = 0.98).$

Non-athletes subjected to long-duration, graded-exercise *tests*. After pooling the data from five trials, the mean effect size was 0.20 (95% CI -0.18, 0.59), which indicates that the dietary NO3 supplementation had a small but non-significant effect on

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Study	SMD	95 % CI	Weight (%)
Lansley et al. (3) ⁽²²⁾	-0.40	-1.34.0.52	1.28
Martin et al. (1) ⁽⁶⁶⁾	-0.36	-1.06, 0.33	2.30
Martin et al. (2) ⁽⁶⁶⁾	-0.29	-0.98, 0.40	2.31
Lane et al. (1) ⁽⁶⁴⁾	-0·19	–0·99, 0·61	1.74
Peacock et al. (28)	-0.17	-1·05, 0·70	1.45
McQuillan et al. (2) ⁽⁶⁷⁾	-0.14	–1.06, 0.78	1.31
Lane et al. (2) ⁶⁴⁾	-0.13	–0·93, 0·66	1.75
McQuillan et al. $(1)^{(67)}$	-0.12	<i>−</i> 1·04, 0·80	1.31
Cermak et al. (1) ⁽²⁷⁾	-0.10	–0·72, 0·51	2.92
Cermak et al. $(2)^{(27)}$	-0.09	–0·71, 0·52	2.92
McQuillan <i>et al.</i> (3) ⁽⁶⁷⁾	-0.09	-1.01, 0.82	1.31
McQuillan <i>et al.</i> (5) ⁽⁶⁷⁾	-0.09	-1.01, 0.83	1.31
McQuillan et al. (6)(67)	-0.07	-0.99, 0.85	1.31
McQuillan et al. (4) ⁽⁴⁷⁾	-0.07	-0.99, 0.85	1.31
Christensen et al. (2) '	-0.05	-0.97, 0.87	1.31
Dimon at $e^{(73)}$	-0.05	-1.03, 0.92	1.00
	-0.04	-0.81, 0.72	1.90
	-0.04	-0.80 0.80	1.75
Lane et al. $(4)^{(64)}$	0.00	-0.80 0.80	1.75
Christensen et al. (1) ⁽⁵²⁾	0.00	-0.87 0.87	1.46
Muggeridge et al. (1) ⁽⁶⁹⁾	0.00	-0.97, 0.97	1.17
McQuillan et al. (7) ⁽⁶⁷⁾	0.00	-0.92, 0.92	1.31
Kramer et al. (1) ⁽⁶³⁾	0.00	-0.80, 0.80	1.75
Hoon et al. (1) ⁽⁶²⁾	0.01	-0.86, 0.88	1.46
Shannon <i>et al.</i> (2) ⁽⁷⁴⁾	0.02	-0.95, 1.00	1.17
Glaister et al. ⁽⁶⁰⁾	0.05	-0·71, 0·76	2.04
Peeling <i>et al.</i> (1) ⁽⁷¹⁾	0.05	–1.10, 1.15	0.82
McQuillan <i>et al.</i> (8) ⁽⁶⁷⁾	0.05	–0·89, 0·95	1.31
Martin et al. (3) ⁽⁰⁰⁾	0.02	–0·66, 0·72	2.34
Bescós et al. (2) ⁽²⁵⁾	0.03	–0·73, 0·80	1.90
Callahan <i>et al.</i> (1) ⁽³³⁾	0.03	–0·94, 1·01	1.17
Callahan et al. (2) ⁽³⁵⁾	0.03	-0.94, 1.01	1.17
Rimer <i>et al.</i> (1)' /	0.05	-0.71, 0.82	1.90
MaQuillen et al. (1) ⁽⁶⁸⁾	0.07	-0.90, 1.06	1.10
Receive at $a(1)^{(25)}$	0.08	-0.69, 1.00	1.00
Thompson et al. $(2)^{(75)}$	0.00	-0.00, -0.00	1.90
Hoon et al. $(2)^{(61)}$	0.11	-0.40 0.63	1.09
Christensen et al. (3) ⁽⁵²⁾	0.11	-0.76 0.99	1.46
Wilkerson et al. (2) ⁽⁷⁶⁾	0.12	-0.85 1.10	1.16
McQuillan <i>et al.</i> (2) ⁽⁶⁸⁾	0.12	-0.85, 1.10	1.16
Hoon <i>et al.</i> (1) ⁽⁶¹⁾	0.12	-0.39, 0.65	4.08
Boorsma et al. (2) ⁽⁵⁸⁾	0.12	-0.85, 1.11	1.16
Lowings et al. ⁽⁶⁵⁾	0.14	-0·73, 1·01	1.45
Cermak et al. (2)(21)	0.14	–0·65, 0·94	1.75
Shannon et al. $(1)^{(74)}$	0.16	–0·81, 1·14	1.16
Cermak <i>et al.</i> (1) ⁽²¹⁾	0.16	–0·63, 0·96	1.74
Hoon et al. $(2)^{(02)}$	0.17	–0·70, 1·05	1.45
Nyakayiru et al. $(1)^{(76)}$	0.18	–0·48, 0·86	2.47
	0.19	-0.78, 1.18	1.16
	0.20	-0.92, 1.34	0.87
Christensen et al. $(1)^{(42)}$	0.23	-0.60, 1.16	1.29
Kramer et al. (1)	0.23	-0.09, 1.10	1.30
Thompson et al. $(1)^{(75)}$	0.24	-0.53, 1.05	1.73
Lansley et al. $(2)^{(22)}$	0.27	-0.65 1.20	1.30
Lansley et al. (4) ⁽²²⁾	0.32	-0.60, 1.25	1.29
Lansley et al. (1) ⁽²²⁾	0.46	-0.47, 1.40	1.27
Peeling et al. (3) ⁽⁷¹⁾	1.11	-0.23, 2.47	0.61
Peeling et al. (4) ⁽⁷¹⁾	2.42	0.70, 4.14	0.38
Overall (1 ² =0.0%, P=1.000)	0.04	-0.05, 0.15	100.00

Fig. 4. Forest plot of physical performance following dietary NO₃ supplementation in athletes. SMD, standardised mean difference.

physical performance (P > 0.05; Fig. 11). According to a fixedeffects analysis, no heterogeneity was observed among these studies $(I^2 = 0\%; Q = 1.38, df = 4, P = 0.84)$.

-4.2

Cyclists. Most tested athletes were cyclists; therefore, this subgroup was subjected to a special analysis in which they were evaluated alone without the inclusion of athletes engaged in other sports. After pooling the data from thirty-seven trials, the effect size mean was 0.04 (95% CI -0.09, 0.17), which indicates that the dietary NO3 supplementation had a negligible and non-significant effect on physical performance (P > 0.05; Fig. 12). According to a fixed-effects analysis, heterogeneity was observed among these studies $(I^2 = 0\%; Q = 4.90, df = 36, P = 1.00).$

Analysis of the relationship between the performance level and the ergogenic response to the NO_3^- supplementation

4.2

By analysing the percentage of trials reporting increased performance in individuals classified into different PL, we observed numerous trials, that is, 50 and 56.5%, showing increased performance in individuals with PL1 and PL2, respectively. In contrast, approximately 37% of the trials involving individuals with PL3 showed an increased performance following the NO₃ supplementation, whereas in trials involving individuals with PL4 and PL5 no improvement in performance was observed following the NO_3^- supplementation (Fig. 13). The χ^2 test showed a different distribution among the PL (P = 0.002).

Study		SMD 95 % CI	Weight (%)
Christensen et al. (1) ⁽⁴²⁾		-0·15 -1·13, 0·84	3.98
Fulford et al. (1) ⁽⁴⁵⁾		-0.12 -1.10, 0.86	3.98
Coggan <i>et al</i> . (1) ⁽⁴³⁾		-0·11 -0·91, 0·69	5.98
Coggan <i>et al</i> . (2) ⁽⁴³⁾	<u> </u>	-0.08 -0.88, 0.72	5.98
Fulford et al. (2) ⁽⁴⁵⁾	<u> </u>	-0.07 -1.05, 0.91	3.99
Wylie <i>et al.</i> (2) ⁽⁵⁷⁾		-0.04 -0.92, 0.83	4.99
Buck et al. ⁽⁴¹⁾		-0.03 -0.53, 0.48	14.97
Wylie <i>et al.</i> (3) ⁽⁵⁷⁾		-0.02 -0.89, 0.86	4.99
Coggan <i>et al.</i> (3) ⁽⁴³⁾	<u> </u>	0.05 -0.75, 0.85	5.99
Coggan <i>et al.</i> (4) ⁽⁴³⁾	<u> </u>	0.16 -0.64, 0.97	5.97
Wylie <i>et al.</i> (1) ⁽⁵⁷⁾		0.21 -0.67, 1.09	4.96
Thompson et al. ⁽⁵³⁾		0.22 -0.48, 0.91	7.94
Christensen <i>et al.</i> (2) ⁽⁴²⁾		0.30 -0.69, 1.28	3.94
Kokkinoplitis and Chester ⁽⁴⁷⁾		0.31 -0.75, 1.36	3.45
Fulford et al. (3) ⁽⁴⁵⁾		0.38 -0.61, 1.37	3.91
Corry <i>et al.</i> ⁽⁴⁴⁾		0.43 -0.46, 1.31	4.87
Kelly <i>et al.</i> (4) ⁽⁴⁶⁾		0.50 -0.44, 1.44	4.34
Mosher <i>et al.</i> ⁽⁴⁸⁾		0.52 -0.30, 1.33	5.78
Overall (1 ² =0.0%, P=0.999)	-	0.12 -0.08, 0.31	100.00
	T		
11		11	
-4.2	0	4.2	

Fig. 5. Forest plot of physical performance during a short-duration test following dietary NO₃⁻ supplementation in non-athletes. SMD, standardised mean difference.

Study		SMD	95 % CI	Weight (%)
Martin <i>et al</i> . (1) ⁽⁶⁶⁾		-0.36	-1.06, 0.34	8.69
Martin <i>et al.</i> (2) ⁽⁶⁶⁾		-0.29	-0·99, 0·41	8.74
McQuillan et al. (2) ⁽⁶⁷⁾		-0.14	−1·07, 0·78	4.96
McQuillan et al. (1) ⁽⁶⁷⁾		-0.12	-1.05, 0.80	4.96
McQuillan et al. (3) ⁽⁶⁷⁾		-0.10	-1.02, 0.83	4.97
McQuillan et al. (4) ⁽⁶⁷⁾		-0.02	−1·00, 0·85	4.97
Christensen <i>et al.</i> (2) ⁽⁴²⁾		-0.02	-0.98, 0.87	4.97
Rimer et al. ⁽⁷³⁾		-0.05	-0.82, 0.72	7.18
Rimer <i>et al</i> . (2) ⁽⁷²⁾		-0.04	-0.81, 0.73	7.18
Martin <i>et al.</i> (3) ⁽⁶⁶⁾		0.03	-0.67, 0.72	8.84
Rimer <i>et al.</i> (1) ⁽⁷²⁾		0.02	-0.72, 0.82	7.18
Lowings <i>et al.</i> ⁽⁶⁵⁾		0.14	-0.74, 1.02	5.51
Christensen <i>et al.</i> (1) ⁽⁴²⁾		0.54	–0·69, 1·16	4.94
Kramer <i>et al</i> . (1) ⁽⁶³⁾		0.52	–0·55, 1·05	6.58
Thompson <i>et al</i> . (2) ⁽⁷⁵⁾		0.27	–0·53, 1·07	6.57
Peeling <i>et al.</i> (3) ⁽⁷¹⁾	-	1.12	-0.24, 2.47	2.31
Peeling <i>et al</i> . (4) ⁽⁷¹⁾	·	2 ·43	0.71, 4.14	1.44
Overall ($I^2 = 0.0\%$, $P = 0.650$)	+	0.03	−0·17, 0·24	100.00
1		1		
-4.2	0	4.2		

Fig. 6. Forest plot of physical performance during a short-duration test following dietary NO3 supplementation in athletes. SMD, standardised mean difference.

Association between supplementation features and changes in physical performance

Pearson's correlation analyses were performed to verify the association between these variables, including the association between changes in physical performance and the dose of NO₃⁻ (non-athletes: r 0.351, P > 0.05; athletes: r 0.099, P > 0.05),

the number of days of supplementation (non-athletes: $r \ 0.166$, P > 0.05; athletes: $r \ 0.114$, P > 0.05) and the total amount ingested (dose multiplied by days under supplementation) (non-athletes: $r \ 0.112$, P > 0.05; athletes: $r \ 0.088$, P > 0.05). No significant correlations were observed between the supplementation features evaluated and changes in physical performance.

Study	SMD	95 % CI	Weight (%)
Vanhatalo et al. ⁽¹⁶⁾	-0.12	−1·10, 0·86	3.35
Vasconcellos et al. ⁽⁵⁵⁾	-0.01	–0·79, 0·78	5.23
Bailey et al. (1) ⁽³⁹⁾	0.03	-1·01, 1·08	2.94
Murphy et al. ⁽⁴⁹⁾	0.05	-0.79, 0.88	4.61
Porcelli et al. (3) ⁽⁵¹⁾	0.07	-1.06, 1.20	2.51
Aucouturier et al. (1) ⁽³⁸⁾	0.09	-0.71, 0.89	5.03
Rienks et al. ⁽⁵²⁾	0.09	–0·84, 1·01	3.77
Porcelli et al. (2) ⁽⁵¹⁾	0.12	-0·93, 1·17	2.93
Thompson et al. ⁽⁵⁴⁾	0.22	-0.47, 0.92	6.67
Wylie <i>et al.</i> ⁽⁵⁶⁾	• 0.23	–0·51, 0·97	5.83
Nyakayiru <i>et al.</i> ⁽⁵⁰⁾	0.26	-0.44, 0.95	6.65
Porcelli et al. (1) ⁽⁵¹⁾	0.31	-0·68, 1·29	3.31
Wylie et al. (1) ⁽¹⁷⁾	0.41	-0·47, 1·30	4·10
Larsen et al. ⁽¹⁵⁾	0.43	–0·51, 1·36	3.68
Aucouturier et al. (2) ⁽³⁸⁾	0.45	-0·36, 1·26	4.90
Wylie et al. (3) ⁽¹⁷⁾	0.51	–0·38, 1·40	4.05
Bailey et al. ⁽¹⁸⁾	0.52	-0.48, 1.52	3.23
Breese et al. ⁽⁴⁰⁾	0.53	–0·41, 1·48	3.63
Wylie et al. (2) ⁽¹⁷⁾	0.54	-0.36, 1.42	4.03
Bailey et al. (2) ⁽³⁹⁾	0.58	–0·49, 1·65	2.80
Bailey et al. ⁽¹⁹⁾	0.59	–0·49, 1·65	2.80
Kelly et al. (3) ⁽⁴⁶⁾	0.62	–0·33, 1·57	3.58
Kelly et al. (2) ⁽⁴⁶⁾	0.64	–0·31, 1·59	3.57
Lansley et al. ⁽²³⁾	0.66	–0·29, 1·62	3.55
Kelly <i>et al.</i> (1) ⁽⁴⁶⁾	1.06	0.06, 2.05	3.26
Overall $(I^2 = 0.0\%, P = 0.999)$	0.34	0.16, 0.52	100.00
1	1		
-4.2	0 4.2		

Fig. 7. Forest plot of physical performance during a long-duration test following dietary NO₃ supplementation in non-athletes. SMD, standardised mean difference.

Publication bias

Publication bias was assessed by a visual inspection of the funnel plot for all subgroups analysed: non-athletes (online Supplementary Fig. S2(a)), athletes (online Supplementary Fig. S1(a)), non-athletes subjected to short-duration tests (online Supplementary Fig. S2(b)), athletes subjected to short-duration tests (online Supplementary Fig. S1(b)), non-athletes subjected to long-duration tests (online Supplementary Fig. S2(c)), athletes subjected to long-duration tests (online Supplementary Fig. S1 (c)), non-athletes subjected to long-duration, open-ended tests (online Supplementary Fig. S3(a)), non-athletes subjected to long-duration time trials (online Supplementary Fig. S3(b)) and non-athletes subjected to long-duration, graded-exercise tests (online Supplementary Fig. S3(c)). These analyses revealed minor asymmetrical inverted distributions that were prominent in all plots, suggesting the presence of a small publication bias.

Risk of bias

The risk of bias was assessed in fifty-four studies (twenty-six and twenty-eight conducted with non-athletes and athletes, respectively) in the systematic review. One study⁽⁷¹⁾ was subjected to two independent evaluations because it presented independent experimental trials. Out of fifty-five evaluations, forty-eight did not present any major risk of bias. Approximately 13% (non-athletes, two studies; athletes, five studies) of the studies did not blind the participants or researchers. In general, the studies evaluated in the present systematic review showed consistent control of the risk of bias and were deemed to be good-quality studies (online Supplementary Tables S3 and S4).

Discussion

The present systematic review and meta-analysis demonstrated that the level of physical fitness is a determining factor in the performance-enhancing effects associated with NO₃ supplementation. Although athletes are usually less prone to benefit from NO3 supplementation, non-athletes can experience small but significant advantages in their physical performance, particularly in performance evaluations using long-duration, openended tests. Interestingly, this effect is not observed using time trials, which is the most ecologically valid exercise protocol⁽⁷⁷⁾. These findings regarding the beneficial effects induced by $NO_3^$ supplementation in non-athletes are supported by the analysis in which the participants were subdivided according to their PL, and those classified at the lower levels (less conditioned) showed more improvements. This information is very important for exercise practitioners and athletes and provides support in decisions regarding whether to use this potential ergogenic aid to improve physical performance and health.

In the present meta-analysis, we observed that individuals with higher fitness levels benefit less from NO_3^- supplementation (Fig. 13). Consistently, the effect size of NO_3^- supplementation-mediated changes on performance in athletes was mostly irrelevant (Fig. 4). In contrast, non-athletes can benefit from NO_3^- supplementation (Fig. 3). This was the first study to systematically show the importance of characterising the fitness levels of

Study	SMD	95 % CI	Weight (%)
Lansley et al. (3)(22)	-0.40	-1·34, 0·53	1.75
Lane <i>et al.</i> (1) ⁽⁶⁴⁾	• –0·19	–0·99, 0·61	2.37
Peacock et al. ⁽²⁸⁾	-0.17	-1·05, 0·70	1.98
Lane <i>et al.</i> (2) ⁽⁶⁴⁾	-0.13	-0.93, 0.67	2.38
Cermak et al. (1) ⁽²⁷⁾	-0.10	-0.72, 0.52	3.97
Cermak et al. (2) ⁽²⁷⁾	-0.10	-0.72, 0.52	3.97
McQuillan et al. (5) ⁽⁶⁷⁾	-0.09	-1.02.0.83	1.78
McQuillan et al. (6) ⁽⁶⁷⁾	-0.07	-1.00, 0.85	1.79
Boorsma et al. (1) ⁽⁵⁸⁾	-0.05	-1.03, 0.93	1.59
Lane <i>et al.</i> (3) ⁽⁶⁴⁾	- 0.00	-0.81, 0.79	2.38
Lane <i>et al.</i> (4) ⁽⁶⁴⁾	- 0.00	-0.80, 0.80	2.38
Christensen et al. (1) ⁽⁵²⁾	- 0.00	-0.88, 0.88	1.99
Muggeridge et al. (1) ⁽⁶⁹⁾		-0.98, 0.98	1.59
McQuillan et al. (7) ⁽⁶⁷⁾	- 0:00	-0.92 0.92	1.79
Kramer et al. (2) ⁽⁶³⁾	- 0.00	-0.80 0.80	2.38
Hoon et al. $(1)^{(62)}$	- 0.01	-0.87 0.89	1.99
Shannon et al. (2) ⁽⁷⁴⁾	- 0.02	_0.96 1.00	1.59
Glaister et al. ⁽⁶⁰⁾	- 0.02	-0.72 0.77	2.78
Peeling et al. $(1)^{(71)}$	0.02	-1.11 1.16	1.19
McOuillan et al. $(8)^{(67)}$	- 0:02	-0.90 0.95	1.79
Bescós et al. $(2)^{(25)}$	- 0:03	-0.73 0.80	2.58
Callaban at $a(1)^{(59)}$	0.03	_0.94 1.02	1.59
Callaban et al. (1)		-0.94,1.02	1.59
Muggeridge et al. $(2)^{(69)}$		-0.91 1.05	1.59
		_0.90 1.07	1.59
Bescós et al. (1) ⁽²⁵⁾	- 0.08	-0.68 0.86	2.58
Thempson at $a(2)^{(75)}$	0.10	_0.70_0.91	2.38
Hoon et al. $(2)^{(61)}$	0.10	-0.41 0.64	5.56
Christenson et al. $(2)^{(52)}$	- 0.11	_0.76_0.99	1.08
Wilkerson et al. $(2)^{(76)}$		-0.86 1.10	1.58
MaQuillon et al. (2) MaQuillon et al. (2) ⁽⁶⁸⁾	0.12	0.96 1.10	1.59
Hoop at al (1) ⁽⁶¹⁾	• 0.12	-0.40 0.65	5.56
Boorema at al. $(2)^{(58)}$	0.12	0.95 1.11	1.59
Cormole at $al_{(2)}^{(21)}$	- 0.12	-0.66 0.95	0.00
	0.14	-0.00, 0.95	2.30
Shannon et al. $(1)^{(25)}$	0.16	-0.82, 1.14	1.29
Leap at $al (0)^{(62)}$	0.18	-0.64, 0.97	2.30
Hoon et al. $(2)^{n-1}$	0.17	-0.70, 1.06	1.98
Nyakayiru et al. (1) ⁽¹⁶⁾	- 0.18	-0.49, 0.86	3.36
	0.19	-0.78, 1.18	1.28
Peeling et al. (2)	0.20	-0.93, 1.34	1.19
	0.23	-0.60, 1.08	2.17
	0.27	-0.66, 1.20	1.77
	0.32	-0.61, 1.25	1.76
	0.46	-0.47, 1.40	1.73
Overall $(I^{-}=0.0\%, P=1.000)$	0.02	<i>–</i> 0·07, 0·17	100.00
	l		
-4·2 0	4.2		

Fig. 8. Forest plot of physical performance during a long-duration test following dietary NO₃ supplementation in athletes. SMD, standardised mean difference.

individuals before adopting a nutritional NO_3^- supplementation ergogenic strategy. Similarly, Porcelli *et al.*⁽⁵¹⁾ assessed athletic performance in subjects with three aerobic fitness levels after 6 d of supplementation with 5.5 mmol per d of NO_3^- . The authors observed that individuals with lower and moderate aerobic capacities performed better during the time trial after the $NO_3^$ supplementation. However, the performance during the time trial was not improved in individuals with a higher aerobic capacity.

Several mechanisms may act collectively to improve performance following NO_3^- supplementation in non-athletes, including beneficial effects of an increased NO bioavailability in the skeletal muscles, blood vessels and even in the brain (Fig. 14). In contrast, the mechanisms underlying the limited ergogenic effects of NO₃ supplementation in high-performance athletes have not been well elucidated. The ergogenic effects of NO₃ supplementation are related to enhanced NO bioavailability, and athletes probably already have optimal levels of NO⁽⁵¹⁾. Highly trained subjects are likely to have high NOS activity⁽⁸³⁾, which might render the NO₃-NO₂-NO pathway less important for NO production. Therefore, the resulting increase in NO bioavailability due to supplementation does not appear to be relevant in athletes. In addition to these factors, Porcelli *et al.*⁽⁵¹⁾ suggested that high-performance athletes have a high daily energy expenditure and possibly an enriched diet. Therefore, a diet consisting of a higher intake of NO₃⁻ in these subjects should be considered. Furthermore, recent evidence that NO₃⁻ supplementation may preferentially alter contractile function in type II fibres⁽⁷⁹⁾ suggests that endurance athletes, who typically have a low proportion of such fibres in their musculature⁽⁸⁴⁾, might experience a blunted physiological response to NO₃⁻ supplementation.

The effects of NO₃⁻ supplementation on exercise performance in non-athletes appear to be more robust in evaluations using longduration, open-ended tests rather than time trials. Time-trial tests are the most ecologically valid options to assess performance^(6,85). Compared with time trials, constant-power (open-ended) tests are more influenced by psychological factors, such as boredom and motivation^(86,87). In addition, open-ended tests are more efficient in measuring endurance capacity rather than exercise performance, which is best measured by time-trial protocols^(6,88).

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Study		SMD	95 % CI	Weight (%)
Bailev <i>et al.</i> (1) ⁽³⁹⁾		0.03	-1.01 1.08	5.39
Aucouturier <i>et al.</i> $(1)^{(38)}$		0.09	-0.71. 0.89	9.23
Nyakayiru <i>et al.</i> ⁽⁵⁰⁾		0.26	-0.44, 0.95	12.21
Wylie <i>et al.</i> (1) ⁽¹⁷⁾		0.41	-0.47, 1.29	7.52
Aucouturier et al. (2) ⁽³⁸⁾	- <u>+</u>	0.45	–0·36, 1·26	8.99
Wylie <i>et al.</i> (3) ⁽¹⁷⁾	-	0.51	–0·38, 1·40	7.43
Bailey et al. ⁽¹⁸⁾		0.52	-0·48, 1·52	5.93
Wylie <i>et al.</i> (2) ⁽¹⁷⁾		0.54	-0·36, 1·42	7.40
Bailey <i>et al.</i> (2) ⁽³⁹⁾		0.58	–0·49, 1·65	5.14
Bailey et al. ⁽¹⁹⁾		0.59	–0·49, 1·65	5.13
Kelly <i>et al.</i> (3) ⁽⁴⁶⁾	1	0.62	–0·33, 1·56	6.57
Kelly <i>et al.</i> (2) ⁽⁴⁶⁾		0.64	–0·31, 1·59	6.55
Lansley et al. ⁽²³⁾		0.66	–0·29, 1·62	6.52
Kelly <i>et al.</i> (1) ⁽⁴⁶⁾		1.06	0.06, 2.05	5.99
Overall (<i>I</i> ² =0.0%, <i>P</i> =0.993)	•	0.47	0.23, 0.71	100.00
7				
-4:2	0	4.2		<u>`</u>

Fig. 9. Forest plot of physical performance during a long-duration open-ended test following dietary NO3 supplementation in non-athletes. SMD, standardised mean difference.

Study		SMD 95 % CI	Weight (%)
Murphy <i>et al.</i> ⁽⁴⁹⁾		0.04 -0.79, 0.88	34.5
Porcelli <i>et al.</i> (3) ⁽⁵¹⁾		0.06 -1.06, 1.19	18·8
Porcelli <i>et al.</i> (2) ⁽⁵¹⁾	*	0.11 -0.94, 1.16	21.9
Porcelli <i>et al.</i> (1) ⁽⁵¹⁾		0.29 -0.70, 1.27	24.7
Overall ($l^2 = 0.0\%$, $P = 0.984$)	+	0.12 -0.37, 0.61	100.00
i 	0	4.2	

Fig. 10. Forest plot of physical performance during a long-duration time trial following dietary NO₃ supplementation in non-athletes. SMD, standardised mean difference.



Fig. 11. Forest plot of physical performance during a long-duration graded-exercise test following dietary NO₃ supplementation in non-athletes. SMD, standardised mean difference.

Study	SMD	95 % CI	Weight (%
Lansley et al. (3) ⁽²²⁾	-0.40	-1·34, 0·52	2.05
Lane et al. (1) ⁽⁶⁴⁾	-0.19	-0·99, 0·61	2.78
McQuillan et al. (2) ⁽⁶⁷⁾	-0.14	-1.06, 0.78	2.09
Lane et al. (2) ⁽⁶⁴⁾	-0.13	-0.93, 0.66	2.79
McQuillan et al. (1) ⁽⁶⁷⁾	-0.12	-1.04, 0.80	2.09
Cermak et al. (1) ⁽²⁷⁾	-0.10	-0.72, 0.51	4.66
Cermak et al. (2) ⁽²⁷⁾	-0.09	-0·71, 0·52	4.66
McQuillan et al. (3) ⁽⁶⁷⁾	-0.09	-1·01, 0.82	2.09
McQuillan et al. (5) ⁽⁶⁷⁾	-0.09	-1·01, 0·83	2.09
McQuillan <i>et al.</i> (6) ⁽⁶⁷⁾	-0.07	-0.99, 0.85	2.09
McQuillan <i>et al.</i> (4) ⁽⁶⁷⁾	-0.07	-0·99, 0·85	2.09
Christensen et al. (4) ⁽⁴²⁾	-0.05	-0·97, 0·87	2.09
Lane et al. (3) ⁽⁶⁴⁾	0.00	-0·80, 0·80	2.80
Lane et al. (4) ⁽⁶⁴⁾	0.00	-0·80, 0·80	2.80
Christensen et al. (1) ⁽⁵²⁾	0.00	–0·87, 0·87	2.33
McQuillan et al. (7) ⁽⁶⁷⁾	0.00	-0.92, 0.92	2.10
Glaister et al. ⁽⁶⁰⁾	0.02	–0·71, 0·76	3.26
McQuillan et al. (8) ⁽⁶⁷⁾	0.05	–0·89, 0·95	2.09
Bescós et al. (2) ⁽²⁵⁾	0.03	-0·73, 0·80	3.03
Callahan <i>et al.</i> (1) ⁽⁵⁹⁾	0.03	–0·94, 1·01	1.86
Callahan et al. (2) ⁽⁵⁹⁾	0.03	–0·94, 1·01	1.86
McQuillan et al. (1) ⁽⁶⁸⁾	0.08	–0·89, 1·06	1.86
Bescós et al. (1) ⁽²⁵⁾	0.08	–0·68, 0·85	3.03
Hoon <i>et al.</i> (2) ⁽⁶¹⁾	0.11	-0·40, 0·63	6.52
Christensen et al. (3) ⁽⁵²⁾	0.11	–0·76, 0·99	2.32
Wilkerson et al. (2) ⁽⁷⁶⁾	0.12	–0·85, 1·10	1.86
McQuillan et al. (2) ⁽⁶⁸⁾	0.12	–0·85, 1·10)	1.86
Hoon <i>et al.</i> (1) ⁽⁶¹⁾	0.12	–0·39, 0·65	6.52
Cermak <i>et al.</i> (2) ⁽²¹⁾	0.14	–0·65, 0·94	2.79
Cermak <i>et al.</i> (1) ⁽²¹⁾	0.16	-0.63, 0.96	2.78
Nyakayiru et al. (1) ⁽⁵⁰⁾	0.18	-0·48, 0·86	3.94
Wilkerson et al. (1) ⁽⁷⁶⁾	0.19	–0·78, 1·18	1.85
Bescós et al. ⁽²⁶⁾	0.23	–0·60, 1·07	2.54
Christensen et al. (3) ⁽⁴²⁾	0.23	–0·69, 1·16	2.08
Lansley et al. (2) ⁽²²⁾	0.27	–0·65, 1·20	2.07
Lansley et al. (4) ⁽²²⁾	0.32	–0·60, 1·25	2.07
Lansley et al. (1) ⁽²²⁾	0.46	–0·47, 1·40	2.03
Overall ($I^2 = 0.0\%, P = 1.000$)	0.04	–0·09, 0·17	100.00
	1		
-4.2 0	4.2		

Fig. 12. Forest plot of physical performance in cyclists following dietary NO₃⁻ supplementation. SMD, standardised mean difference.

Although the dietary NO_3^- supplementation did not exert positive effects on the performance of athletes as previously described, the use of this supplement in sports competitions may still be applicable. During competitions, the winner is often determined by narrow differences between athletes, thus creating opportunities for the implementation of practices that may have subtle improvements in performance. Therefore, the distinct sensitivity of different athletes to supplementation should not be disregarded^(7,76) and further research on this topic is warranted.

It is important to understand the physiological meaning of the doses that were supplemented in the included studies. These doses ranged from 4.0 to 19.5 mmol (Tables 1 and 2). Considering that the daily ingestion of NO₃⁻ corresponds on average to 91 mg (1.5 mmol) in people from the UK⁽⁸⁹⁾, the supplementation would increase the daily ingestion of nitrate by 3- to 13-fold in this population. However, the dose of the NO₃⁻ supplementation, the number of days of supplementation and the total amount ingested do not appear to influence the effects of NO₃⁻ supplementation on physical performance in non-athletes and athletes as shown by the lack of significant associations between these parameters. Studies using a single dose showed that NO₃⁻ supplementation had either no effects^(17,53,56) on exercise performance. Likewise,



Fig. 13. Number of trials with increased performance (%) in subjects with different performance levels (PL).

studies using several days (\geq 5 d) of supplementation showed that NO₃⁻ supplementation had either no effects^(19,39,45,57) or positive effects^(18,22,40,46) on exercise performance. A similar rationale can be applied to the supplementation dose, which does not appear to influence physical performance.



Fig. 14. Mechanisms underlying improved physical performance induced by nitrate (NO_3^-) supplementation in non-athletes subjected to prolonged, open-ended tests. Through a series of reduction reactions along the gastrointestinal tract and at target tissues, NO_3^- acts as the main nitric oxide (NO) donor. Increased NO bioavailability promotes beneficial effects on performance through effects in skeletal muscles, blood vessels and likely in the brain. To date, no study has provided direct evidence showing that NO_3^- supplementation increases brain NO levels (this is the reason why a dashed line is connecting NO to the brain in the schematic). In the skeletal muscles, NO_3^- acts and increases local blood flow⁽⁸⁰⁾. In the blood vessels, NO increases cutaneous heat loss⁽⁸¹⁾ and reduces blood pressure⁽⁸²⁾. Experiments conducted in rats showed that NO in the brain reduces the oxygen cost of exercise⁽¹⁰⁾, attenuates exercise-induced hyperthermia^(11,13) and increases cutaneous heat loss⁽¹³⁾. Collectively, these physiological responses induced by NO_3^- supplementation improve performance in the conditions mentioned above.

For example, studies using low doses (4–5·5 mmol) showed that NO_3^- supplementation had either no effects^(17,19,38,51) or positive effects^(16,51,53,56) on exercise performance. Finally, studies using high doses (>10 mmol) also showed that NO_3^- supplementation had no effects^(43,45,52) or positive effects^(17,43) on exercise performance.

Despite the high variability in the experimental protocols used in the studies analysed in the present review, the analysed subgroups did not include heterogeneous samples. Therefore, the data homogeneity, the quality of the studies assessed by the risk of bias and the absence of publication bias in the studies used in this systematic review and meta-analysis are sufficient to draw conclusions.

A major limitation of this review is related to the wide variation in the methods (differences in the dose of NO_3^- , number of days of supplementation, total amount ingested and mode of $NO_3^$ delivery) used in the analysed studies. This methodological diversity complicates the interpretation of the results and precludes clear conclusions regarding certain features of supplementation, such as those listed above. In addition, most studied individuals were men, and whether a sex-related sensitivity to the enhancing effects of nitrate exists in nonathletes is unclear. Thus, future studies should include women as participants.

Practical applications

The present results may encourage coaches, athletes and exercise practitioners to consider the following: (1) NO_3^- supplementation appears to be more effective in non-athletes than in athletes, particularly in performance evaluations using long-duration, open-ended tests; (2) the ergogenic effects mediated by NO_3^- supplementation do not affect physical performance in athletes, including cyclists, which are the most studied athletic population; and (3) subjects classified at a lower PL (i.e. less conditioned) are more responsive to the effects of NO_3^- supplementation than are subjects classified at a higher PL.

Conclusion

The present systematic review and meta-analysis indicates that dietary NO_3^- supplementation improves physical performance in non-athletes, particularly in performance evaluations using long-duration, open-ended tests. In contrast, dietary NO_3^- supplementation does not appear to benefit the performance of athletes.

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The authors declare that there are no conflicts of interest.

Supplementary material

For supplementary material/s referred to in this article, please visit http://dx.doi.org/10.1017/S0007114518000132

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