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Abstract: Quercetin is a dietary flavonoid reported to increase mitochondrial biogenesis or potentially acting as a stimulant due to adenosine receptor antagonist properties; however, whether this translates into improved human endurance exercise performance is not clear to date. **PURPOSE:** To perform a systematic review of the literature and a meta-analysis to examine whether quercetin ingestion increases aerobic capacity and endurance exercise performance in humans. **METHODS:** A search of the literature was conducted using the keywords: quercetin, performance, exercise, endurance, and aerobic capacity. Eleven studies were identified as meeting the inclusion criteria providing data on 254 subjects. Mean $\dot{V}O_2\text{max}$ ranged among studies from 41-64 ml/kg/min (across all studies, median = 47.3). Among studies, median treatment duration was 14 d at a median dosage of 1083 mg per d. Effect sizes (ES) were calculated as the standardized mean difference and meta-analyses were completed using a random-effects model. **RESULTS:** The ES calculated for all studies combined indicates a small, beneficial effect (~3%) favoring quercetin over placebo (ES=0.269; $p=0.006$). Using a subgroup meta-analysis, the overall ES (0.340) for the comparisons assessing quercetin versus placebo on endurance exercise performance was not found to be statistically different ($p=0.423$) from the overall ES (0.186) for the comparisons on $\dot{V}O_2\text{max}$. Meta-regression of study ES against subject fitness level or level of plasma quercetin achieved by supplementation failed to find significant relationships. **CONCLUSION:** Despite variability among studies, quercetin provides a small but significant benefit in physiological measures of human endurance exercise capacity ($\dot{V}O_2\text{max}$ and endurance exercise performance). Moreover, the variability in ES among studies cannot be explained by any one factor at present.

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Quercetin improves aerobic capacity and endurance performance: a meta-analysis

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Abstract

Quercetin is a dietary flavonoid reported to increase mitochondrial biogenesis or potentially acting as a stimulant due to adenosine receptor antagonist properties; however, whether this translates into improved human endurance exercise performance is not clear to date. **PURPOSE:** To perform a systematic review of the literature and a meta-analysis to examine whether quercetin ingestion increases aerobic capacity and endurance exercise performance in humans. **METHODS:** A search of the literature was conducted using the keywords: quercetin, performance, exercise, endurance, and aerobic capacity. Eleven studies were identified as meeting the inclusion criteria providing data on 254 subjects. Mean $\dot{V}O_{2\max}$ ranged among studies from 41-64 ml/kg/min (across all studies, median = 47.3). Among studies, median treatment duration was 14 d at a median dosage of 1083 mg per d. Effect sizes (*ES*) were calculated as the standardized mean difference and meta-analyses were completed using a random-effects model. **RESULTS:** The *ES* calculated for all studies combined indicates a small, beneficial effect (~3%) favoring quercetin over placebo (*ES*=0.269; *p*=.006). Using a subgroup meta-analysis, the overall *ES* (0.340) for the comparisons assessing quercetin versus placebo on endurance exercise performance was not found to be statistically different (*p*=.423) from the overall *ES* (0.186) for the comparisons on $\dot{V}O_{2\max}$. Meta-regression of study *ES* against subject fitness level or level of plasma quercetin achieved by supplementation failed to find significant relationships. **CONCLUSION:** Despite variability among studies, quercetin provides a small but significant benefit in physiological measures of human endurance exercise capacity ($\dot{V}O_{2\max}$ and endurance exercise performance). Moreover, the variability in *ES* among studies cannot be explained by any one factor at present.

KEY WORDS: SPORTS NUTRITION, AEROBIC CAPACITY, FLAVONOIDS, EXERCISE

Paragraph Number 1 Quercetin is a polyphenolic flavonoid, a natural component in several plant foods (e.g., skin of grapes, onions, apples) (3, 14, 25). The first investigation on quercetin administration in humans was published in 1975 (22) and the number of publications has increased dramatically over the past decade. Quercetin is generally recognized as safe by the U.S. Food and Drug Administration and there are several purported health and physiological benefits of quercetin administration including cardioprotective, anticarcinogenic, antioxidant, antiapoptotic, and ergogenic properties (6, 7, 9, 13, 18, 26, 39). However, in order to augment plasma quercetin levels ($> 1 \mu\text{M}$), supplemental forms of quercetin are needed and, therefore quercetin supplementation has become of interest to the military, athletic and elderly populations (14).

Paragraph Number 2 Although much research has focused upon quercetin's antioxidant potential (7, 17, 24, 26, 33, 41, 42), several recent investigations have examined exercise performance with quercetin supplementation. The interest in performance has stemmed largely from impressive results obtained in the mouse where 7 d of quercetin supplementation (12.5-25 mg/kg body weight) was associated with greater time to fatigue (40% increase during treadmill running) and volitional physical activity (wheel running) paralleling increased expression of markers of mitochondrial biogenesis (peroxisome proliferator-activated receptor coactivator (PGC)-1 α and sirtuin (SIRT)1) as well as increased mitochondrial DNA (15). To our knowledge, the only other published study, to date, investigating markers of mitochondrial biogenesis in humans ($n = 26$) following quercetin administration (1000 g/d for 2 weeks) observed similar trends in markers of mitochondrial biogenesis, but failed to reach statistical significance (39).

Therefore, whether quercetin can enhance growth of mitochondria in humans remains to be determined.

Paragraph Number 3 The first human exercise study investigating quercetin supplementation was published in 2006 (32) with several more studies being published more recently. Several studies have reported increased endurance exercise capacity and performance in humans following ingestion of quercetin (13, 32, 39) while others have failed to find statistically significant benefits in either endurance exercise performance or aerobic capacity ((2, 10, 12, 19, 20, 38, 43, 45). Potential reasons for inconsistent findings among these studies may include differing subject fitness levels (i.e., greater effects of quercetin potentially for lower fit subjects), differences in plasma quercetin concentration obtained via the various supplementation protocol/supplement types, and/or differences in research designs.

Paragraph Number 4 We therefore concluded that a combined systematic review and meta-analytic approach would be advantageous to assess quercetin's effect on aerobic exercise capacity and endurance exercise performance in humans. The equivocal nature of the modest, but mounting, available literature deserves quantification of an overall effect size of quercetin impact on endurance exercise in humans and, if possible, determination of the primary factors that may explain the variability in results among studies. Therefore, the purpose of this investigation was to conduct a systematic review of the literature and a meta-analysis to identify quercetin's effect on endurance exercise capacity (i.e., assessed by either maximal oxygen uptake ($\dot{V}O_{2max}$) and/or endurance exercise performance). Moreover, we sought to determine if factors such as subject fitness level or the plasma quercetin concentration obtained with supplementation could explain variability among study findings.

METHODS

Systematic Review

Paragraph Number 5 A thorough, systematic search of the research literature was performed for the effects of quercetin ingestion on endurance exercise capacity. For the purposes of this review, endurance exercise capacity was divided into two subcategories: 1) $\dot{V}O_{2max}$, operationally defined as peak oxygen uptake achieved during an incremental exercise test to volitional exhaustion and, 2) endurance exercise performance, operationally defined as maximal effort exerted during continuous exercise of ≥ 10 min duration. The literature search began January 2010 and continued through July 2010. PubMed, SportDiscus, ISI Web of Knowledge, ProQuest Dissertation & Theses, and the American College of Sports Medicine database of annual meeting proceedings were searched. The search terms were quercetin and performance, exercise, endurance, aerobic capacity and oxygen uptake. The retrieved studies were delimited to those involving human subjects. Reference lists from the 22 fully evaluated publications and those of relevant review articles (14) were also examined for studies not found with the online database searches.

Study inclusion and exclusion criteria.

Paragraph Number 6 Studies meeting the following criteria were considered for review: 1) the study was conducted on humans, 2) the study had at least two trials (or separate groups of subjects) in which quercetin was consumed in one trial (or group) and placebo in the other, and 3) a test of endurance exercise capacity (as defined above) was measured. Studies were excluded for the following: 1) the effect observed in a study could not be attributed specifically to

quercetin (e.g., the two conditions differed by more than quercetin with the other ingredients known to improve performance with supplementation), or 2) when insufficient data were reported in a study to calculate an effect size (*ES*) for either $\dot{V}O_{2\max}$ or endurance exercise performance. For such studies, we attempted to retrieve the necessary data by contacting the corresponding author by e-mail and/or telephone.

Selection of studies.

Paragraph Number 7 In total, 1610 publications were originally identified by the database searches and review of article reference lists. However, 1588 were initially excluded based on the title and/or review of the abstract or because they were redundant results in different searches. Twenty-two publications were fully evaluated. Based on the inclusion/exclusion criteria, 11 articles/abstracts were excluded, which left a total of 11 articles/abstracts that were included in the meta-analyses.

Data extraction and study quality assessment.

Paragraph Number 8 For the meta-analysis, either $\dot{V}O_{2\max}$ and/or endurance exercise performance data were extracted in the form of means, standard deviations (*SD*), and sample sizes for quercetin and placebo conditions. These descriptors were reported for pre- and post-treatment values in cross-over studies where subjects served as their own control and also in independent quercetin- and placebo-treatment groups. If available, individual subject data were retrieved in order to calculate intertrial correlations for $\dot{V}O_{2\max}$ or endurance exercise performance. If a study included any treatment condition other than quercetin and placebo, the data for those conditions were omitted for the purpose of the meta-analysis. All 11 studies were

assessed for quality on the basis of the Physiotherapy Evidence-Based Database Scale (PEDro). The scale yields a total possible score of 11 points, with a greater score corresponding to higher quality (34).

Meta-Analysis

Paragraph Number 9 $\dot{V}O_{2\max}$ and endurance exercise performance data comparing the quercetin and placebo conditions were converted to a standard format by calculating the standardized mean difference, heretofore referred to as the effect size (*ES*). For crossover studies ($n = 7$) in which means, *SD* (or standard errors), and sample sizes were reported (10, 13, 19, 20, 32, 39, 43) the paired difference (i.e., quercetin mean – placebo mean) and the paired difference *SD* (i.e., $(\text{quercetin } SD^2 + \text{placebo } SD^2 - 2 \times \text{intertrial correlation} \times \text{quercetin } SD \times \text{placebo } SD)^{1/2}$) were initially calculated. These were used to calculate the standardized mean difference (i.e., $\text{paired difference} \times (2(1 - \text{intertrial correlation}))^{1/2} / \text{paired difference } SD$) and standardized mean difference SE (i.e., $(1/n + \text{standardized mean difference}^2 / (2n))^{1/2} (2(1 - \text{intertrial correlation}))^{1/2}$). Study intertrial correlations were calculated from individual data. If individual data were not published, authors provided the correlations or individual data. For those studies where correlational data could not be obtained and were needed to compute *ES* ($n = 2$), the respective median intertrial correlation was substituted in the calculation. Median (min-max) intertrial correlations were 0.95 (0.90-0.99) and 0.82 (0.78-0.96) for $\dot{V}O_{2\max}$ and endurance performance, respectively. For the studies (2, 12, 38, 45) using a randomized controlled trial design with independent groups (placebo and quercetin), standardized mean differences were calculated as detailed by Borenstein (5). In studies (19, 43) that measured $\dot{V}O_{2\max}$ in the same subjects across multiple time points during the treatment (quercetin administration), standardized

mean differences and variances were averaged across these time points. In studies that evaluated more than one experimental factor level (e.g., quercetin dosage of 1000 and 1400 mg/d for independent subject groups compared to a single placebo group (38) or if the two outcomes of endurance exercise performance and $\dot{V}O_{2\max}$ were measured in the same subjects (12, 13, 43), the *ES* was calculated for each comparison or outcome, respectively, and the mean computed as a single *ES*. Meta-analyses were run with a random-effects model that accounts for true interstudy variation in effects as well as for random error within each study (4). A random-effects model was chosen over a fixed-effect because of the inter-study variation in experimental factor levels (e.g., quercetin dosage, subject population, method of assessing endurance exercise performance) used in the studies. Individual studies are given a relative weight in the meta-analysis for their influence on the overall *ES*; consequently, a percent change score was estimated by subtracting the mean of the placebo from the mean of the quercetin condition divided by the mean of the placebo condition in each study but summed according to the weighted percentage each study contributed to the meta-analysis to yield a composite ‘descriptive’ percentage change score.

Moderator variables.

Paragraph Number 10 We also sought to determine the role of experimental factors in explaining the inter-study variation observed in *ES*. These experimental factors were treated as moderator variables in the meta-analysis. A subgroup meta-analysis (i.e., meta-analyses comparing subsets of studies using Q tests on the basis of ANOVA) was used to probe potential moderator variables such as whether the *ES* was influenced by the type of assessment ($\dot{V}O_{2\max}$ test vs. endurance exercise performance test), and whether the study was published or not. Meta-regression (using a method-of-moments model) was used to assess the relationship between

study *ES* and subject fitness level or the plasma quercetin level achieved with supplementation. Meta-analyses and meta-regression were conducted with the Comprehensive Meta-analysis software (Version 2.2; Biostat Inc., Englewood, NJ). An alpha level of 0.05 was used to indicate statistical significance in all analyses. *ES* of 0.2, 0.5, and 0.8 were considered to be small, moderate, and large, respectively (11); an *ES* of 0.1 was considered trivial. The effect of publication bias on the meta-analyses was addressed by combining a funnel plot assessment with the Duval and Tweedie's trim and fill correction (16). This is a preferred method for assessing the extent of publication bias (i.e., the tendency for negative or non-significant findings to not be published resulting in an inflated overall *ES*) as well as for making a correction to the overall *ES*.

RESULTS

Description of included studies.

Paragraph Number 11 In total, 11 studies were included for the meta-analysis examining quercetin's effects on $\dot{V}O_{2\max}$ ($n = 6$) and endurance exercise performance ($n = 8$), three of which measured both $\dot{V}O_{2\max}$ and performance. The characteristics of those investigations are summarized in Table 1. Eight studies were published in peer-reviewed journals. Four studies reported being funded by a commercial interest (12, 32, 38, 39). Seven studies used a within-subjects cross-over experimental research design, with the other four employing a randomized controlled trial with two independent groups. In total, 254 subjects participated in the 11 studies; 129 and 194 subjects were assessed via $\dot{V}O_{2\max}$ and/or endurance performance, respectively (51 did both). The median number of subjects per study was 12 (range: 9-58). Mean $\dot{V}O_{2\max}$ among studies ranged from 41-64 ml/kg/min (across all studies, median = 47.3). Five studies used only male subjects, whereas six included both male and female subjects. There were no studies

performed on only females. Most subjects were young adults (< 30 y), except for one study which included subjects up to 50 y (45). The median daily quercetin dosage was 1000 (min-max: 600-2000) mg over a median duration of 11 (min-max: 1-54) d. The PEDro quality scores for all studies were ≥ 8 . Only two studies had a score below the maximum score of 11 due to lack of details reported in the methods.

Endurance exercise capacity meta-analysis.

Paragraph Number 12 The overall summary effect for the meta-analysis which combined both measures of endurance exercise capacity ($\dot{V}O_{2\max}$ and endurance exercise performance) across the 11 studies yielded a statistically significant but small overall *ES*, indicating quercetin supplementation improves endurance exercise capacity (overall *ES* = 0.269, $p = .006$; Fig. 1). This *ES* equated approximately to a 3% improvement in performance after ingestion of quercetin compared with placebo. However, considerable variation in *ES* was observed among studies probing the effect of quercetin ingestion on $\dot{V}O_{2\max}$, endurance exercise performance or both with *ES* ranging from -0.098 (10) to 1.095 (39). Two studies (13, 39) illustrated in Figure 1 favored placebo over quercetin (a negative *ES* that lies to the left of the zero line in Fig. 1) while the symbols for the other studies fell to the right of zero although most of the associated 95% CI crossed the zero line. Figure 2 illustrates the impact on the *ES* when a single study is removed from the meta-analysis. Although the overall *ES* is reduced below the threshold indicative of a “small effect” (*ES* < 0.2) when the Nieman 2010 study (39) is removed, the overall *ES* remained significant ($p < .05$). Moreover, the removal of any other single study did not alter the “small” magnitude of *ES*.

Paragraph Number 13 Publication bias was assessed by examining the funnel plot of study *ES* versus standard error. No significant asymmetry was detected, and therefore a Duval and Tweedie's trim and fill correction did not alter overall *ES*. Publication bias was also assessed by a subgroup meta-analysis comparing the overall *ES* of published studies versus that of the unpublished studies we were able to identify. Since unpublished studies tend to yield non-significant and/or negative findings (and therefore are often not published), it was predicted that the *ES* would be lower for unpublished studies. This was the case with the *ES* tending to be higher ($p = .066$) for the published studies ($ES = 0.355$) compared to the unpublished studies ($ES = 0.048$). In fact, the magnitude of *ES* for the three unpublished studies is considered below trivial ($ES < 0.1$).

Moderator variables influence on *ES*.

Paragraph Number 14 Due to substantial *ES* dispersion among the studies, additional probing of experimental factors was performed. A subgroup meta-analysis (Figure 3) determined whether the *ES* for studies assessing $\dot{V}O_{2\max}$ differed from those using endurance exercise performance tests. The benefit of quercetin for $\dot{V}O_{2\max}$ ($ES = 0.186$) and endurance exercise performance ($ES = 0.340$), were not significantly different from each other ($p = .423$).

Paragraph Number 15 Meta-regression was used to assess whether the variability in study *ES* could be explained by an experimental factor that was a continuous variable. The relationships between study *ES* and two factors (plasma quercetin level obtained via supplementation and subject fitness level) were determined. There was no significant association of either subject fitness level with study *ES* ($p = .902$) or plasma [quercetin] with study *ES* ($p =$

.142). The trend for an inverse association between plasma [quercetin] and *ES* is presented in Figure 4. Unfortunately, several studies (13, 19, 32) did not report plasma [quercetin].

DISCUSSION

Paragraph Number 16 The main finding of this study is that quercetin supplementation can improve human endurance exercise capacity ($\dot{V}O_{2\max}$ and endurance exercise performance). However, this benefit is small in magnitude (i.e., ~3%). Variation in study *ES* was not significantly associated with the moderator variables probed such as subject fitness level or the plasma [quercetin] achieved with supplementation. Because quercetin versus placebo comparisons in the meta-analyses were based on experimental, within-study research designs (i.e., each study in a meta-analysis had both quercetin and placebo conditions/groups that were randomly assigned), one can make cause-and effect claims regarding the effect of quercetin.

Paragraph Number 17 Potential limitations of the present systematic review and meta-analyses include relatively few overall studies in the analysis, possible publication bias despite inclusion of unpublished studies, lack of intertrial correlations from some of the studies and limited data on potential moderator variables. The inclusion of unpublished data is open to question as these have not been rigorously peer-reviewed. However, the peer-review filter is not perfect. Including unpublished data can alter meta-analysis findings such that statistical significance is lost, highlighting the possibility that the published literature may be affected by selective reporting biases (31). Therefore, it has been recommended that results of studies from the “gray literature” (i.e., literature not published in peer reviewed journals) also be included in meta-analyses (29). Thus, three abstracts were included in the meta-analysis. There are no

apparent reasons why these studies are not yet published, at least concerning the quality of the studies gauged by the PEDro scoring system. Our results indicated that the overall *ES* for the unpublished studies was trivial, insignificant and tended to be significantly lower than that for the published studies. Thus, inclusion of unpublished studies did not introduce bias toward finding a benefit of quercetin supplementation on endurance exercise capacity since the effect was just the opposite, i.e., a reduction in the overall *ES*. Publication bias takes place when research that is reflected in the published literature is systematically unrepresentative of the population of completed studies (44). In general there is the tendency for investigations with non-significant and/or negative findings to not be published (23, 28). Meta-analyses, therefore, tend to be based to a larger extent on published data due to the difficulty of identifying unpublished studies and retrieving the data necessary to calculate an *ES*. As a result, the overall *ES* tends to be inflated in a meta-analysis if an inadequate search is conducted and not all completed studies are included.

Paragraph Number 18 Not knowing the intertrial correlations in some of the crossover studies is a commonly occurring difficulty in meta-analysis research (4) since most primary research studies neither report this correlation nor the data necessary to calculate it. In order to adjust for the missing correlation, Borenstein et al. (4) recommend that a sensitivity analysis be conducted by assessing the effect of varying the assumed intertrial correlations in applicable studies. An estimated intertrial correlation was needed to calculate *ES* in only two studies. All other studies either did not require this correlation (randomized controlled trial with independent groups) or the information was provided by the authors. Our sensitivity analysis manipulated the correlations ranging from the observed minimum to maximum values (versus a derived median

value); yet, the overall *ES* was negligibly impacted (i.e., a minimum *ES* of 0.268 that was still highly significant $p \leq 0.007$).

Physiological rationale and future investigations

Paragraph Number 19 There are currently two proposed mechanisms by which quercetin could exert its ergogenic properties. The one that has received the most attention is quercetin's potential to induce mitochondrial biogenesis (through PGC-1 α), which in turn would increase oxidative capacity and subsequently endurance performance. In addition, SIRT1 which activates PGC-1 α by deacetylation is also induced by quercetin and increased levels of SIRT1 and PGC-1 α coincided with increased levels of mitochondrial DNA after quercetin supplementation in mice (15). However, similar increases in markers of mitochondrial biogenesis have not yet been successfully demonstrated in humans. Further research is merited to determine what supplementation regimen (quercetin dose, duration, or co-ingestion with other nutrients) could significantly increase mitochondrial biogenesis. If quercetin acts through mitochondrial biogenesis, it stands to reason that highly fit subjects with already elevated mitochondrial density would be less likely to obtain benefits, whereas subjects with low fitness levels (and therefore presumed low mitochondrial densities) would be more likely to benefit from quercetin administration. However, our meta-regression analysis did not reveal a significant correlation between subject fitness level and study *ES*, although the range of $\dot{V}O_{2\max}$ was 41-64 ml/kg/min, with no study including subjects of very low fitness. Whether impaired mitochondrial density and/or extremely reduced fitness (as observed with aging) are important mediators of quercetin's effects remains to be determined.

Paragraph Number 20 A second proposed mechanism for ergogenic effects of quercetin is the antagonism of adenosine receptors. Other adenosine receptor antagonists (i.e. caffeine) have performance-enhancing effects on endurance potentially via the central nervous system as reviewed elsewhere (8, 21) and it is possible that quercetin could act in a similar manner (1, 30, 46) at concentrations that are achievable in plasma with oral administration of common doses (10, 27, 33, 35-38, 40, 45, 46). However, the meta-regression analysis (Figure 4) showed no significant correlation between plasma quercetin concentration and study *ES*, and, in fact, higher levels of quercetin in the blood tended to be associated with lower study *ES*. With relatively few studies measuring plasma [quercetin], it remains difficult to discern the optimal plasma [quercetin] that could prove to be advantageous (or disadvantageous) for performance. Future research may further our understanding related to what mechanism(s) account for observed effects in humans.

Paragraph Number 21 In conclusion, despite conflicting results among investigations regarding the effect of quercetin supplementation on endurance exercise capacity, the current meta-analysis of available literature indicates that there is a small, but significant ergogenic benefit. The variation among study *ES* does not appear to be associated with factors such as the fitness level of the subjects studied or plasma concentrations obtained with quercetin supplementation. However, the available data are still limited in scope, particularly related to subject population (young, healthy, and physically active individuals), leaving the possibility that in individuals with compromised mitochondrial densities, quercetin may exert additional benefits. Future investigations are merited to ascertain for whom and at what plasma concentration benefits may be obtained.

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Conflict of Interest

No conflict of interest present.

The results of the present study do not constitute endorsement by ACSM

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Figure Captions

Figure 1: Forest plot of effect sizes from 11 studies that assessed the effect of quercetin ingestion on either $\dot{V}O_{2max}$, endurance exercise performance or combined if both were measured in the same study. A square represents the effect size for each study and its size is proportional to the study's weighting in the meta-analysis. The horizontal lines represent the 95% confidence interval (CI) for each effect. Studies are arranged from top to bottom by the effect size magnitude. The diamond at the bottom represents the overall effect size calculated using a random-effects model. The diamond's width represents the 95% CI for the overall effect size.

Figure 2: Forest plot of overall effect size when one study is removed. The horizontal lines represent the 95% confidence interval for an overall effect without the study listed. The bottom diamond is the same overall effect size as depicted in Figure 1 when all studies are included. Note that the overall effect size remains significant regardless of which study is removed.

Figure 3: Forest plot of effect sizes for subgroup meta-analysis comparing the effect of quercetin supplementation on endurance exercise performance (9 effect sizes) with that of $\dot{V}O_{2max}$ (bottom 6 effect sizes). The diamonds represent the overall effect size for each sub-group.

Figure 4: Meta-regression analysis of the relationship between plasma quercetin concentration reported in a study and study effect size (*ES*). Each study is depicted by a circle and the circle size represents the degree of weighting for that study. The line of best fit was not statistically different from zero ($p = .115$).

Table 1

TABLE 1. Characteristics of the 11 studies examining the effect of quercetin ingestion on aerobic exercise capacity and/or endurance exercise performance.

Reference	Publication Type	Research Design	Subject Info	Subject Fitness Level (ml/kg/min)	Quercetin Dosage (mg/d)	Suppl. Period (d)	[Plasma] (μM)	Type of Measure	PEDro Quality Score
Bigelman et al. (20)	Doctoral dissertation	Double blind, independent groups	22 male and 7 female moderately trained	48.7 ± 5.6	1000	42-54	1.9 ± 1.7	$\dot{V}O_{2\text{max}}$	11
Cheuvront et al. (22)	Published, peer reviewed	Double blind, crossover	10 moderately fit males	45.2 (40.5-55.2)	2000	1	7.7 ± 3.8	15 min performance cycling	11
Cureton et al. (21)	Published, peer reviewed	Double blind, independent groups	30 untrained males	41.6 ± 5.3	1000	7	0.5 ± 0.5	$\dot{V}O_{2\text{peak}}$, 10 min performance cycling	11
Davis et al. (9)	Published, peer reviewed	Double blind, crossover	7 male, 5 female active but not highly trained	45.5 ± 4.5	1000	7	N/A	$\dot{V}O_{2\text{peak}}$, Cycling to fatigue @ 75% $\dot{V}O_{2\text{peak}}$	11
Freese et al. (25)	Conference Presentation	Double blind, crossover	9 recreationally active male and female	44.0 ± 6.4	1000	7-49	N/A	$\dot{V}O_{2\text{max}}$	8
Ganio et al. (19)	Published, peer reviewed	Double blind, crossover	5 male and 6 female untrained	45.1 ± 10.9	1000	5	3.7 ± 1.8	$\dot{V}O_{2\text{max}}$	11
McRae et al. (18)	Published, peer reviewed	Double blind, crossover	12 elite male cyclists	64.4 ± 6.7	600	42	N/A	30 km cycling TT	11

Nieman et al. (10)	Published, peer reviewed	Double blind, crossover	30 untrained males	46.3 ± 6.1	1000	14	0.9 ± 0.2	12 min performance run (15% incline)	11
Nieman et al. (23)	Published, peer reviewed	Double blind, independent groups	32 male, 7 female trained cyclists	60.6 ± 7.6	1000 and 1400	14	1.8 ± 1.2 and 2.4 ± 1.9	Mean of 5, 10 and 20 km TT	11
Sharp et al. (26)	Published Abstract	Double blind, crossover	9 male soldiers	49.7 ± 5.8	1000	8.5	1.1 ± 1.0	$\dot{V}O_{2max}$, 200 kJ performance cycling	10
Utter et al. (27)	Published, peer reviewed	Double blind, independent groups	39 experienced male/female ultramarathoners	N/A	1000	21	2.2 ± 0.4*	160 km run	11

Suppl., supplementation; [Plasma], plasma concentration; PEDro, Physiotherapy Evidence-Based Database Scale; TT, time trial; N/A, not available.

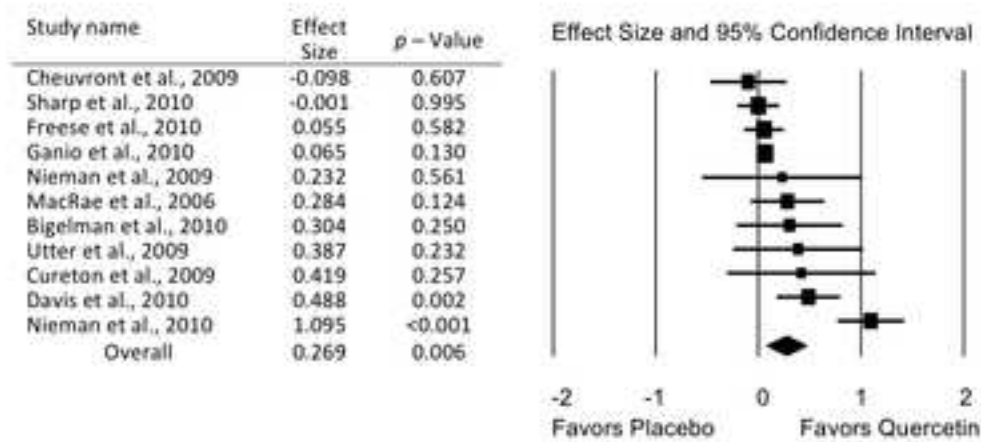
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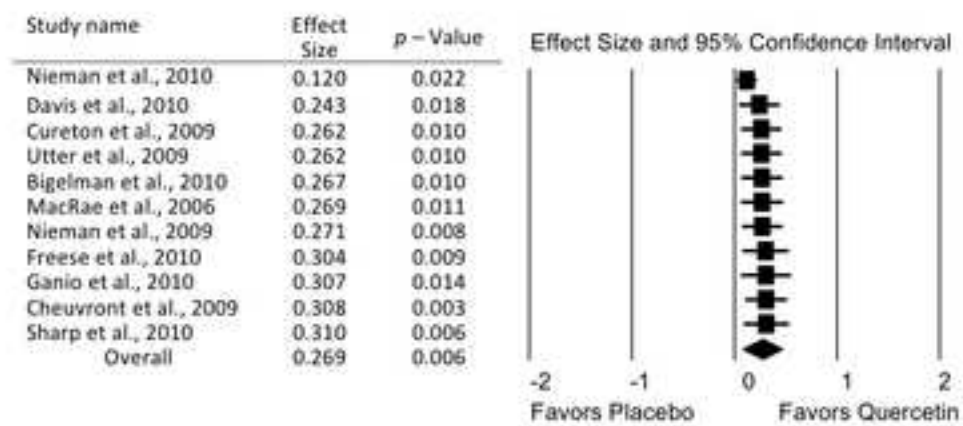
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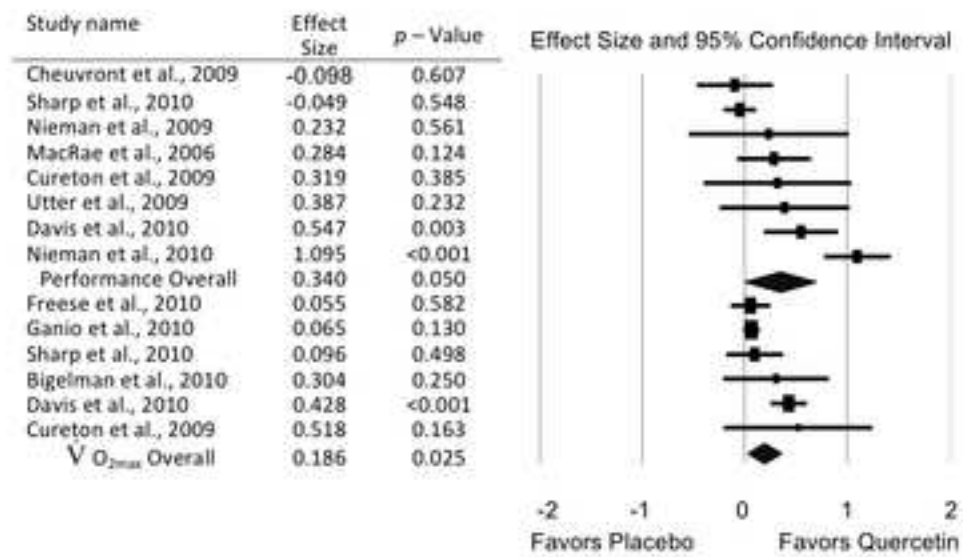
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Figure 4

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