SYSTEMATIC REVIEW

Effects of Exercise Training on Anabolic and Catabolic Hormones with Advanced Age: A Systematic Review

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Abstract

Background Ageing is accompanied by decreases in physical capacity and physiological regulatory mechanisms including altered hormonal regulation compared with age-matched sedentary people. The potential benefits of exercise in restoring such altered hormone production and secretion compared to age-matched physically inactive individuals who are ageing remains unclear.

Objectives The aim of this systematic review was to summarise the findings of exercise training in modulating levels of ostensibly anabolic and catabolic hormones in adults aged > 40 years.

Methods We searched the following electronic databases (to July 2021) without a period limit: Cochrane Library, PubMed, Science Direct, Scopus, SPORTDiscus and Web of Science. Additionally, a manual search for published studies in Google Scholar was conducted for analysis of the ‘grey literature’ (information produced outside of traditional commercial or academic publishing and distribution channels). The initial search used the terms ‘ageing’ OR ‘advanced age’ OR ‘old people’ OR ‘older’ OR ‘elderly’ AND ‘anabolic hormones’ OR ‘catabolic hormones’ OR ‘steroid hormones’ OR ‘sex hormones’ OR ‘testosterone’ OR ‘cortisol’ OR ‘insulin’ OR ‘insulin-like growth factor-1’ OR ‘IGF-1’ OR ‘sex hormone-binding globulin’ OR ‘SHBG’ OR ‘growth hormone’ OR ‘hGH’ OR ‘dehydroepiandrosterone’ OR ‘DHEA’ OR ‘dehydroepiandrosterone sulfate (DHEA-S)’ AND ‘exercise training’ OR ‘endurance training’ OR ‘resistance training’ OR ‘strength training’ OR ‘weight-lifting’ OR ‘high-intensity interval training’ OR ‘high-intensity interval exercise’ OR ‘high-intensity intermittent training’ OR ‘high-intensity intermittent exercise’ OR ‘interval aerobic training’ OR ‘interval aerobic exercise’ OR ‘intermittent aerobic training’ OR ‘intermittent aerobic exercise’ OR ‘high-intensity training’ OR ‘high-intensity exercise’ OR ‘sprint interval training’ OR ‘sprint interval exercise’ OR ‘combined exercise training’ OR ‘anaerobic training’. Only eligible full texts in English or French were considered for analysis.

Results Our search identified 484 records, which led to 33 studies for inclusion in the analysis. Different exercise training programs were used with nine studies using endurance training programs, ten studies examining the effects of high-intensity interval training, and 14 studies investigating the effects of resistance training. Most training programs lasted ≥ 2 weeks. Studies, regardless of the design, duration or intensity of exercise training, reported increases in testosterone, sex hormone-binding globulin (SHBG), insulin-like growth factor-1 (IGF-1), human growth hormone (hGH) or dehydroepiandrosterone (DHEA) (effect size: 0.19 < d < 3.37, small to very large) in both older males and females. However, there was no consensus on the effects of exercise on changes in cortisol and insulin in older adults.

Conclusion In conclusion, findings from this systematic review suggest that exercise training increases basal levels of testosterone, IGF-1, SHBG, hGH and DHEA in both male and females over 40 years of age. The increases in blood levels of these hormones were independent of the mode, duration and intensity of the training programs. However, the effects of long-term exercise training on cortisol and insulin levels in elderly people are less clear.

1 Introduction

Ageing is characterized by decreases in physical capacity that are related to a loss of muscle mass and decreased muscle contraction velocity [1] and maximum strength, which
According to Korhonen et al. [4], strength and muscle volume peaks around ~30 years of age and decreases by 15% per decade from age 50 onwards, until 70 years of age, when strength diminishes its anabolic effects in skeletal muscle, and so negatively impacts neuromuscular performance [17], muscle mass and bone mineral density [18].

Ageing alters metabolism and degradation of hormones, especially in those individuals with decreased liver or kidney function [19]. In addition, ageing reduces target cell hormone receptor number, affinity and signal transduction [20, 21]. Moreover, anabolic hormones such as testosterone inhibit the secretion of cortisol, diminishing glucocorticoid-mediated catabolism of skeletal muscle, meaning testosterone has both anabolic and anti-catabolic effects [22–24]. Nearly 98% of circulating testosterone is bound to sex hormone-binding globulin (SHBG) and albumin [25], both of which are also altered by the ageing process [26]. As the concentration of SHBG increases with age, the level of free (unbound) and bioavailable (bound loosely to albumin) testosterone decreases, so that there is less testosterone available for tissue uptake [27]. Interestingly, there are similar patterns of androgenic hormone decline (andropause) and somatotropin hormone decline (somatopause); the latter also have anabolic actions [14]. Specifically, human growth hormone (hGH) and its main downstream protein, insulin-like growth factor-1 (IGF-1), decrease with advanced age [14]. Secretion of hGH decreases by ~14% per decade after 20 years of age [14], and reaches, by the age of ~60 years, half of the hGH secretion of younger counterparts (20–30 years) [28]. The main stimulated protein downstream of hGH, IGF-1, as already noted, also decreases with age (~10% per decade) [28]. IGF-1 is also anabolic in nature, increases cell proliferation, cell differentiation and energy metabolism, and prevents apoptosis [29].

Although endocrine dysregulation is associated with advanced age, it is difficult to attribute this alteration to age exclusively, as physical activity and exercise also influence the hormonal milieu [19]. Age is associated with physical inactivity [30], which can influence the age-endocrine dysregulation relationship. While ageing per se may not cause endocrinological dysregulation, age-associated increases in sedentary behaviour could [31–34]. Exercise is a non-pharmacological strategy to counteract some of the physiological changes that occur with age, including endocrine changes [19, 35–40].

Exercise exerts well-known health-promoting cardioprotective effects [41], with recent meta-analytical evidence demonstrating running activities were associated with a 30% reduction in cardiovascular mortality [42]. This emphasizes the importance of physical activity for health, supporting the recent narrative by the UK government that identified the importance of physical activity for health, supporting the recent narrative by the UK government that identified a curvilinear dose–response relationship between physical activity and health outcomes [43]. Moreover, several reports or opinion pieces suggest exercise may be a countermeasure to human biological ageing [44]. Thus, exercise and physical activity ameliorate many deleterious effects of chronological ageing on multiple physiological systems. There are some reports that lifelong exercisers are more phenotypically younger in terms of endocrinological profile than their sedentary counterparts, and exercise interventions result in a ‘younger’ hormonal profile than before undertaking exercise [45]. Therefore, it appears consistent physical exercise may be required to maintain endocrine function with ageing. However, before exercise can be proposed as a viable countermeasure to endocrinological dysregulation, it is important to consider the existing literature in terms of methodologies,
quality of research and heterogeneity, and conduct a sys-

Inetic review of available literature. To the best of our

knowledge, only one narrative review [19] and two book

chapters [46, 47] have reviewed the effects of physical exer-
cise on changes in anabolic and catabolic hormones in older

adults. Therefore, it seemed prudent to conduct a systematic
review of the effects of various exercise training protocols

on ostensibly anabolic and catabolic hormones in people

aged > 40 years with normal body mass.

2 Methods

2.1 Eligibility Criteria

Population, Intervention, Comparison, Outcome and Study
design (PICOS) criteria were used for inclusion of studies in
this review (see Table 1) [48]. This systematic review included
original studies (randomized or non-randomized) for which the
full texts were available and that performed interventions with
exercise training, included 2 or more weeks of follow-up, and
involved subjects who were aged between 40 and 85 years. We
included studies that involved one or both sexes, and specifi-
cally evaluated blood levels of any of the following hormones:
total testosterone, cortisol, insulin, IGF-1, SHBG, hGH, dehy-
droepiandrosterone (DHEA) and dehydroepiandrosterone sul-
fate (DHEA-S) before and after exercise.

Duplicate publications or sub-topics of included studies
[e.g., studies involving co-morbidities or pathologies, and
studies linking exercise to nutritional interventions (e.g.,
nutrition counselling, balanced or hypocaloric diets, and
supplements)] or pharmacological agents were all excluded
to reduce confounding factors [49]. Studies involving indi-
viduals with overweight or obese BMIs (BMI ≥ 25 kg/m²]
were also excluded [49].

2.2 Literature Search Strategy

This systematic review is reported in accordance with the
Preferred Reporting Items for Systematic Reviews and Meta-
Analyses (PRISMA) statement and the Cochrane Handbook
for Systematic Reviews of Interventions [50]. The study
protocol was registered (CRD42019138269) in the Interna-
tional Prospective Register of Systematic Reviews (PROS-
PERO) platform.

We searched the following electronic databases (to July
2021) without a period limit: Cochrane Library, PubMed,
Science Direct, Scopus, SPORTDiscus and Web of Sci-
ence. Additionally, a manual search for published studies
in Google Scholar was conducted for analysis of the ‘grey
literature’ (information produced outside of traditional com-
ercial or academic publishing and distribution channels).
The initial search used the terms ‘ageing’ OR ‘advanced age’
OR ‘old people’ OR ‘older’ OR elderly’ AND ‘anabolic hor-
mones’ OR ‘catabolic hormones’ OR ‘steroid hormones’ OR
‘sex hormones’ OR ‘testosterone’ OR ‘cortisol’ OR ‘insulin’
OR ‘insulin-like growth factor-1’ OR ‘IGF-1’ OR ‘sex hor-
mone-binding globulin’ OR ‘SHBG’ OR ‘growth hormone’
OR ‘hGH’ OR ‘dehydroepiandrosterone’ OR ‘DHEA’ OR
‘dehydroepiandrosterone sulfate (DHEA-S)’ AND ‘exercise
training’ OR ‘endurance training’ OR ‘resistance training’
OR ‘strength training’ OR ‘weight-lifting’ OR ‘high-inten-
sity interval training’ OR ‘high-intensity interval exercise’
OR ‘high-intensity intermittent training’ OR ‘high-intensity
intermittent exercise’ OR ‘interval aerobic exercise’ OR ‘interval aerobic training’ OR
‘interval aerobic exercise’ OR ‘interval aerobic training’
OR ‘intermittent aerobic exercise’ OR ‘anaerobic training’. Only eligible full texts in
English or French were considered for analysis.

2.3 Study Selection and Data Extraction

Three authors independently performed searches in the elec-
tronic databases, and disagreements were resolved by con-
sensus. The literature search strategies used for all databases
are available in the supporting information.

The data-collection process is shown in Fig. 1 [51].
Titles and abstracts of selected articles were independently
assessed by two researchers (HZ and AJ). The reviewers
were not blinded to the authors, institutions or journals
associated with the studies. Abstracts that provided insuf-
cient information on inclusion and exclusion criteria were

| Table 1 PICOS (participants, interventions, comparisons, outcomes, study design) |
|-------------------------------------------|
| PICOS component | Details |
| Participants | Healthy humans aged: > 40 and < 85 years |
| Interventions | Exercise training with two or more weeks of follow-up |
| Comparisons | Control group/Untrained participants |
| Outcomes | Physical performances, anabolic/catabolic hormone responses |
| Study designs | nRCTs, nRnCTs and RCTs |
retrieved for full-text analysis. Furthermore, the researchers independently analysed the full text and determined the eligibility of the studies, and disagreements were resolved by consensus. The agreement rate between the reviewers was 97% for the eligibility criteria of the study.

Corresponding authors of publications were contacted to avoid duplicate-counting of participants or to clarify questions about the methods where necessary. The corresponding authors were also contacted to provide data that may not have been included in the publications. Two researchers (HZ and AJ) independently performed the data extraction, and disagreements were resolved by consensus. Data were extracted for pre- and post-training hormone levels.

### 2.4 Assessment of Risk of Bias

The quality of studies was assessed using the Physiotherapy Evidence Database (PEDro) scale (http://www.pedro.fhs.usyd.edu.au), which has good reliability and validity [52]. The PEDro scale has 11 possible points that examine external validity (criterion 1) and internal validity (criteria 2–9) of controlled trials, and also enable determination of whether there was sufficient statistical information for interpreting results (criteria 10–11). The items of the scale are: (1) eligibility criteria were specified; (2) subjects were randomly allocated to groups; (3) allocation was concealed; (4) groups were similar at baseline; (5) subjects were blinded; (6) therapists who administered the treatment were blinded; (7) assessors were blinded; (8) measures of key outcomes were obtained from more than 85% of subjects; (9) data were analysed by intention to treat; (10) statistical comparisons between groups were conducted; and (11) point measures and measures of variability were provided. The first criterion is not included in the final score. Moreover, because of the nature of the physical activity interventions, where patient and therapy blinding and allocation are unlikely, the

![Fig. 1](image-url) Selection process for research articles (n=33) included in this systematic review. Adapted version of the recommendations in the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement [43]
total score a trial could receive was limited to eight points. A cut-off of six points on the PEDro scale signified high-quality studies, as this has been reported to be sufficient to determine high-quality versus low-quality studies [52]. The studies were evaluated by two experienced investigators (HZ and AJ), and in the event of disagreement a third reviewer (ACH) was invited to further review the findings.

2.5 Data Analysis

The percent change (Δ%) was calculated (if not available in the study) for each study to evaluate the magnitude of the effects using the following equation:

\[ \Delta\% = \frac{(M_{\text{post}} - M_{\text{pre}})}{M_{\text{pre}}} \times 100 \]

where \( M_{\text{post}} \) represents the mean value after (acute exercise or long-term of training) and \( M_{\text{pre}} \) represents the baseline mean value.

Effect sizes (ES) were computed to present standardized effects of acute and long-term training on the outcome variables (e.g., hormones and physical performance). The ES was calculated with Cohen’s \( d \) [53] by dividing the raw ES (difference in means) by the pooled standard deviations:

\[ \text{ES} = (\text{Cohen’s } d) = \frac{(M_1 - M_2)}{\text{SD pooled}} \]

Values for ES were defined as trivial (<0.2), small (0.2–0.6), moderate (0.6–1.2), large (1.2–2.0) and very large > 2 [54]. Results for each outcome variable are presented with number of observations (\( N \)), Δ% and ES. Data analysis was processed using SigmaStat 3.5 software (Systat, Inc, San Jose, CA, USA). The ES and Δ% were analysed in studies where sufficient data were available. A significant difference was indicated when the 95% confidence interval (CI) of the ES did not overlap zero.

3 Results

3.1 Study Selection

Our search identified 484 studies related to the effects of exercise on hormone levels in adults over 40 years of age (Fig. 1). After screening of titles, abstracts and full texts, 33 studies were selected for inclusion in our final analysis, and the characteristics of these long-term studies are summarised in Table 2. The 33 studies were carried out in different countries from five continents (Africa, North America, Europe, Asia and Australia). Fifteen studies investigated only male subjects, ten studied female subjects exclusively, while eight studies investigated both males and females.

A total of 2211 participants (age range = 40–85 years) underwent exercise-training programs and completed the studies. The 33 studies used different exercise-training protocols, with nine studies using endurance-training programs, ten studies examining the effects of high-intensity interval training (HIIT) and 14 studies investigating the effects of resistance training. The training duration lasted at least 2 weeks [4], but several studies used ~12 weeks, and four studies used a 52-week exercise protocol [55, 56]. Studies were generally classified as ‘high-quality’ studies (mean 6.9 in the PEDro scale score) (Table 3).

3.2 Total Testosterone

Twelve studies investigated the effects of training on testosterone concentrations in older adults [16, 57–67] (Table 4). Irrespective of the exercise protocol (type of exercise, duration or intensity of exercise training), these studies all reported increases in basal total testosterone in both male and female participants (effect size: 0.19 < \( d < 3.37 \), small to very large).

3.3 Cortisol

Nine studies investigated the effects of exercise training on cortisol in older adults (Table 5). Six studies reported increases in basal cortisol concentrations [15, 16, 58, 64, 67, 68] (effect size: 0.27 < \( d < 2.69 \), small to very large), while three studies observed decreases [62, 63, 69] (effect size: 0.27 < \( d < 0.46 \), small).

3.4 Insulin

The effects of long-term training on insulin concentrations in older adults are summarised in Table 6. Nine studies [15, 64, 65, 70–74] reported decreased basal insulin (effect size: 0.04 < \( d < 2.30 \), small to very large) and four studies [4, 69, 75, 76] observed increased concentrations (effect size: 0.32 < \( d < 0.56 \), small).

3.5 Insulin-Like Growth Factor-1 (IGF-1)

Nine studies investigated the effects of training on IGF-1 concentrations in older adults (Table 7). Among these, eight studies reported significant increases in IGF-1 in both elderly males and females (effect size: 0.27 < \( d < 1.03 \), small to moderate) [65, 66, 69, 72, 77–80] and one study reported decreased IGF-1 [73] (effect size: 1.06).

3.6 Sex Hormone-Binding Globulin (SHBG)

Studies of the effects of training on SHBG concentrations in older adults are summarised in Table 8. Six studies [15, 55, 60–63] reported increases in basal SHBG concentrations in elderly women and men irrespective of the type, duration
| Study           | Year | PEDro scale | Population/sex/sample size | Sample size | Country      | Age, years (mean ± SD) or age range | Characteristics of exercise training          | Duration (weeks) |
|-----------------|------|-------------|---------------------------|-------------|--------------|-------------------------------------|-----------------------------------------------|-----------------|
| Friedenreih et al. [69] | 2019 | 8           | Post-menopausal women     | 396         | Canada       | 59.4 ± 4.9                          | Moderate and high-intensity training           | 52              |
| Vaczi et al. [59]       | 2014 | 7           | Older men                 | 16          | Hungary      | 65.7 ± 5.3                          | Stretch shortening cycle and eccentric training | 10              |
| Im et al. [10]          | 2019 | 7           | Older women               | 25          | Korea        | 69.4 ± 2.9                          | Yoga and Korean dance                          | 12              |
| Søgaard et al. [77]     | 2018 | 6           | Older men and women       | 22          | Denmark      | 63 ± 1                              | High-intensity interval training               | 6               |
| Ahtiainen et al. [60]   | 2011 | 7           | Older men                 | 35          | Finland      | 61 ± 5                              | Heavy resistance exercise                      | 21              |
| Ahtiainen et al. [61]   | 2015 | 7           | Older men                 | 13          | Finland      | 70 ± 2                              | Heavy resistance exercise                      | 52              |
| Banitalebi et al. [70]  | 2018 | 9           | Older women               | 48          | Iran         | 67.4 ± 1.4                          | Resistance and endurance training              | 12              |
| Consitt et al. [76]     | 2016 | 7           | Young and older           | 20          | USA          | 19–29 and 57–82                     | Endurance and strength training                | 12              |
| DiPietro et al. [63]    | 2008 | 7           | Older women               | 20          | USA          | 77 ± 6                              | Aerobic training and strength training         | 36              |
| Glintborg et al. [62]   | 2013 | 10          | Older males               | 54          | Denmark      | 68                                  | Strength training                              | 12              |
| Ha et al. [72]          | 2018 | 7           | Older women               | 20          | North Korea  | 73 ± 2.8                            | Combined resistance training and aerobic training | 12              |
| Hayes et al. [63]       | 2015 | 7           | Older men                 | 48          | Scotland     | 61 ± 5                              | Low- to medium- and high-intensity training    | 6               |
| Hayes et al. [90]       | 2015 | 6           | Sedentary aged men        | 22          | UK           | 62 ± 2                              | High-intensity training                        | 6               |
| Kim et al. [56]         | 2017 | 7           | Older men and women       | 555         | USA          | 51                                  | Moderate physical activity                     | 52              |
| Krishnan et al. [65]    | 2013 | 7           | Premenopausal women       | 28          | USA          | 46.7 ± 3.3                          | Aerobic and resistance training                | 24              |
| Micielska et al. [73]   | 2019 | 6           | Healthy inactive women    | 33          | Poland       | 45 ± 13                             | High-intensity circuit training                | 5               |
| Motiani et al. [55]     | 2017 | 7           | Sedentary men and women   | 26          | Finland      | 45–55                               | Moderate-intensity interval training           | 2               |
| Nunes et al. [66]       | 2019 | 7           | Post-menopausal women     | 34          | Brazil       | 64.2                                | Resistance training                            | 16              |
| Ogawa et al. [74]       | 2010 | 6           | Older women               | 21          | Japan        | 85.0 ± 4.5                          | Resistance training                            | 12              |
| De Guia et al. [94]     | 2019 | 6           | Older men                 | 43          | Denmark      | 46.5 ± 3.0                          | Aerobic and resistance training                | 12              |
| Praksch et al. [78]     | 2019 | 7           | Older women               | 60          | Hungary      | 67.4 ± 5                            | Home-based walking and aerobic training        | 12              |
| Ramos et al. [75]       | 2016 | 7           | Elderly men and women     | 66          | Australia    | 58 ± 7                              | MICT and high-intensity training               | 16              |
| Sato et al. [67]        | 2014 | 6           | Older men                 | 19          | Japan        | 67.2 ± 1.8                          | Resistance training                            | 12              |
| Sellami et al. [15]     | 2016 | 7           | Moderately trained late adult men | 36       | Tunisia     | 40.7 ± 1.8                          | Combined sprint and resistance training        | 13              |
and intensity of exercise training (effect size: 0.25 < d < 1.68, small to large).

### 3.7 Growth Hormone (hGH)

Only four studies investigated the effects of long-term training on basal hGH concentrations in older adults [67, 69, 73, 81] (Table 9). These studies reported increases in hGH in response to physical training (effect size: 0.29 < d < 2.58, small to very large).

### 3.8 Dehydroepiandrosterone (DHEA) and Dehydroepiandrosterone Sulfate (DHEA-S)

Studies examining the effects of long-term training on basal DHEA concentrations in older adults are summarised in Table 10. Six studies [10, 55, 64, 66, 78, 82] reported increases in DHEA in older males and females (effect size: 0.37 < d < 1.71, small to large). Only one study [65] reported a decrease (effect size: 0.28, small) in DHEA in post-menopausal women in response to 16 weeks of resistance training.

### 4 Discussion

This systematic review indicates that exercise training increases basal total testosterone, IGF-1, SHBG, hGH, DHEA and DHEA-S in males and females ≥ 40 years of age. Effects of exercise on blood hormones occurred regardless of the type, duration and intensity of training programs, with the exception of a lack of consensus on the effects of long-term exercise training on cortisol and insulin responses in older adults (Fig. 2).

### 4.1 Effect of Exercise on Testosterone Levels

Exercise tended to produce small to large increases in total testosterone, supporting the supposition that exercise is the most convenient non-pharmacological means of increasing testosterone production and concomitantly preventing muscle loss in the elderly [60]. Different forms of exercise training can increase testosterone [60], although this finding is not ubiquitous [32, 83]. For example, 6 weeks of progressive resistance exercise increased muscle testosterone levels in the elderly, due to increased muscle steroidogenesis [66]. This corresponded to increased blood free testosterone, although total testosterone was not reported as commonly measured by other investigations, which may explain the divergency of results. Herbert et al. [33] previously reported that exercise increased free testosterone but not total testosterone levels [33]. Preconditioning exercise (10% increase) and HIIT (7% increase) combined to increase total testosterone by 17% in previously sedentary males, but only increased free testosterone by 5% [63]. Thus, the fraction of testosterone measured may result in different findings between studies, as supported by a recent meta-analysis of exercise-induced testosterone changes that concluded that free testosterone, rather than total testosterone, was more likely to change following resistance exercise [83].

The findings of this systematic review suggest exercise increases blood testosterone in both males and females, although several studies suggest men were more likely to benefit from exercise training in terms of increased total
| Study | Year | Eligibility criteria | Randomized allocation | Blinded allocation | Group Homogeneity | Blinded subjects | Blinded therapists | Blinded assessor | Drop out ≥ 15% | Intention-to-treat analysis | Between-group comparison | Point estimates and variability | PEDro sum |
|-------|------|----------------------|-----------------------|-------------------|------------------|----------------|------------------|----------------|---------------|-----------------------------|----------------------|--------------------------------|---------|
| Aerobic—endurance training |       |                      |                       |                   |                  |                |                  |                |               |                             |                      |                                |         |
| Bennefoy et al. [82] | 1999 | ●                    | ○                     | ○                 | ●                | ○              | ●               | ●              | ○             | ●                          |                      |                                | 6        |
| Consitt et al. [76] | 2016 | ●                    | ●                     | ○                 | ○                | ○              | ●               | ●              | ○             | ●                          |                      |                                | 7        |
| DiPietro et al. [71] | 2008 | ●                    | ●                     | ○                 | ○                | ○              | ●               | ●              | ○             | ●                          |                      |                                | 7        |
| Kim et al. [56] | 2017 | ●                    | ●                     | ○                 | ○                | ○              | ●               | ●              | ○             | ●                          |                      |                                | 7        |
| Krishnan et al. [65] | 2014 | ●                    | ●                     | ○                 | ○                | ○              | ●               | ●              | ○             | ●                          |                      |                                | 7        |
| Praksch et al. [78] | 2019 | ●                    | ●                     | ○                 | ○                | ○              | ●               | ●              | ○             | ●                          |                      |                                | 7        |
| Yamada et al. [79] | 2015 | ●                    | ●                     | ○                 | ○                | ○              | ●               | ●              | ○             | ●                          |                      |                                | 7        |
| Im et al. [10] | 2019 | ●                    | ●                     | ○                 | ○                | ○              | ●               | ●              | ○             | ●                          |                      |                                | 7        |
| High-intensity interval training |       |                      |                       |                   |                  |                |                  |                |               |                             |                      |                                |         |
| Friedenreich et al. [69] | 2019 | ●                    | ●                     | ○                 | ○                | ●              | ●               | ●              | ●             | ●                          |                      |                                | 8        |
| Vaczi et al. [59] | 2014 | ●                    | ●                     | ○                 | ○                | ○              | ●               | ●              | ○             | ●                          |                      |                                | 7        |
| Sogaard et al. [77] | 2019 | ●                    | ●                     | ○                 | ○                | ○              | ●               | ●              | ○             | ●                          |                      |                                | 6        |
| Hayes et al. [63] | 2015 | ●                    | ●                     | ○                 | ○                | ○              | ●               | ●              | ○             | ●                          |                      |                                | 7        |
| Hayes et al. [90] | 2017 | ●                    | ○                     | ○                 | ○                | ○              | ●               | ●              | ○             | ●                          |                      |                                | 6        |
| Micielska et al. [73] | 2019 | ●                    | ○                     | ○                 | ○                | ○              | ●               | ●              | ○             | ●                          |                      |                                | 6        |
| Motiani et al. [55] | 2017 | ●                    | ●                     | ○                 | ○                | ○              | ●               | ●              | ○             | ●                          |                      |                                | 7        |
| Ramos et al. [75] | 2016 | ●                    | ●                     | ○                 | ○                | ○              | ●               | ●              | ○             | ●                          |                      |                                | 7        |
| Sellami et al. [15] | 2016 | ●                    | ●                     | ○                 | ○                | ○              | ●               | ●              | ○             | ●                          |                      |                                | 7        |
| Resistance training |       |                      |                       |                   |                  |                |                  |                |               |                             |                      |                                |         |
| Ahtiainen et al. [60] | 2011 | ●                    | ●                     | ○                 | ○                | ○              | ●               | ●              | ○             | ●                          |                      |                                | 7        |
| Ahtiainen et al. [61] | 2015 | ●                    | ●                     | ○                 | ○                | ○              | ●               | ●              | ○             | ●                          |                      |                                | 7        |
| Banitalebi et al. [70] | 2018 | ●                    | ●                     | ●                 | ●                | ○              | ●               | ●              | ○             | ●                          |                      |                                | 9        |
| Bermon et al. [80] | 1999 | ●                    | ○                     | ○                 | ○                | ○              | ●               | ●              | ○             | ●                          |                      |                                | 6        |
| Craig et al. [58] | 1989 | ●                    | ○                     | ○                 | ○                | ○              | ●               | ●              | ○             | ●                          |                      |                                | 6        |
| Glintborg et al. [62] | 2013 | ●                    | ●                     | ●                 | ●                | ●              | ●               | ●              | ○             | ●                          |                      |                                | 10       |
| Ha et al. [72] | 2018 | ●                    | ●                     | ○                 | ○                | ○              | ●               | ●              | ○             | ●                          |                      |                                | 7        |
| Nunes et al. [66] | 2019 | ●                    | ●                     | ○                 | ○                | ○              | ●               | ●              | ○             | ●                          |                      |                                | 7        |
| Ogawa et al. [74] | 2010 | ●                    | ○                     | ○                 | ○                | ○              | ●               | ●              | ○             | ●                          |                      |                                | 6        |
| Sato et al. [67] | 2014 | ●                    | ○                     | ○                 | ○                | ○              | ●               | ●              | ○             | ●                          |                      |                                | 6        |
| Sellami et al. [16] | 2018 | ●                    | ●                     | ○                 | ○                | ○              | ●               | ●              | ○             | ●                          |                      |                                | 7        |
| Walker et al. [68] | 2015 | ●                    | ●                     | ○                 | ○                | ○              | ●               | ●              | ○             | ●                          |                      |                                | 7        |
testosterone [59–61, 63]. Yet, benefits of exercise training in both sexes stretch beyond steroidogenesis, and include effects such as muscle mass regeneration, weight loss, disability prevention and prevention of sarcopenia [64, 65]. Differences in exercise training, such as type, intensity, frequency and duration, can potentially affect testosterone levels and muscle mass, with exercise volume being a critical component [84]. Results from this review demonstrate different forms of exercise (such as resistance training, HIIT, aerobic training) aid in maintenance of blood testosterone levels and muscle mass of the elderly. Levels of free testosterone, representing the fraction available for tissue uptake, are increased by exercise when total testosterone levels increase with no changes in SHBG levels [16]. There is much interest in regulation of testosterone levels in the aged as low testosterone is associated with many non-communicable diseases such as diabetes [85], cardiovascular disease [86], Alzheimer’s disease [87], dementia [88], obesity [89] and ultimately mortality [86]. Evidence of increases in circulating testosterone (particularly the free fraction) by non-pharmacological means (e.g., exercise) has important implications for patients and clinicians [66, 67, 90]. Nevertheless, it remains unclear if increases in blood testosterone through exercise: (a) exceed inherent analytical and biological variability [91], and (b) exert benefits on ageing physiology in addition to the other effects of exercise.

### 4.2 Effects of Exercise on Cortisol

The results of our analysis indicate that effect sizes have qualitative differences [i.e., the direction of the effect (increase or decrease)] in the various studies, ranging from

| Reference(s) | Year | Intervention | Population | Outcomes | Effect size |
|--------------|------|--------------|------------|----------|-------------|
| Ahtiainen et al. [60] | 2011 | Heavy resistance exercise | 61 ± 5 | Male | Testosterone ↑ | 0.38 |
| Ahtiainen et al. [61] | 2015 | Heavy resistance exercise | 70 ± 2 | Male | Testosterone ↑ | 1.99 |
| Craig et al. [58] | 1989 | Progressive resistance training | 62.8 ± 0.7 | Male | Testosterone ↑ | 0.40 |
| Glintborg et al. [62] | 2013 | Strength training | 68–78 | Male | Testosterone ↑ | 0.90 |
| Hayes et al. [63] | 2015 | Low to medium and high intensity training | 61 ± 5 | Male | Testosterone ↑ | 0.22 |
| Hayes et al. [90] | 2015 | High-intensity interval training | 62 ± 2 | Male | Testosterone ↑ | 0.24 |
| Krishnan et al. [65] | 2014 | Aerobic and resistance training | 46.7 ± 3.3 | Female | Testosterone ↑ | 0.19 |
| Nunes et al. [66] | 2019 | Resistance training | 64.2 | Female | Testosterone ↑ | 0.29 |
| Sato et al. [67] | 2014 | Resistance training | 67.2 ± 1.8 | Male | Testosterone ↑ | 3.37 |
| Sellami et al. [16] | 2018 | Combined sprint and resistance training | 40 ± 2 | Male | Testosterone ↑ | 1.60 |
| Vaczi et al. [59] | 2014 | Stretch shortening cycle and eccentric training | 65.7 ± 5.3 | Male | Testosterone ↑ | 0.32 |
| Walker et al. [68] | 2015 | Resistance training | 63.7 ± 3 | Male | Testosterone ↑ | 0.39 |

† Indicates increase, ‡ indicates decrease

| Reference(s) | Year | Intervention | Population | Outcomes | Effect size |
|--------------|------|--------------|------------|----------|-------------|
| Banitalebi et al. [70] | 2018 | Resistance and endurance training | 67.3 ± 1.4 | Female | Cortisol ↓ | 0.27 |
| Friedenreich et al. [69] | 2019 | Moderate- and high-intensity training | 59.4 ± 4.9 | Female | Cortisol ↑ | 2.69 |
| Hayes et al. [63] | 2015 | Low- to medium- and high-intensity training | 61 ± 5 | Male | Cortisol ↓ | 0.39 |
| Hayes et al. [90] | 2015 | High-intensity training | 62 ± 2 | Male | Cortisol ↓ | 0.46 |
| Nunes et al. [66] | 2019 | Resistance training | 64.2 ± 1.2 | Female | Cortisol ↑ | 0.31 |
| Sellami et al. [15] | 2016 | High-intensity sprint training and strength training | 40.7 ± 1.8 | Male | Cortisol ↑ | 0.98 |
| Sellami et al. [16] | 2018 | Combined sprint and resistance training | 40 ± 2 | Male | Cortisol ↑ | 0.27 |
| Vaczi et al. [59] | 2014 | Stretch shortening cycle and eccentric training | 65.7 ± 5.3 | Male | Cortisol ↑ | 0.37 |
| Walker et al. [68] | 2015 | Resistance training | 63.7 ± 3 | Male | Cortisol ↑ | 0.38 |

† Indicates increase, ‡ indicates decrease
Table 6  Effects of training on insulin concentrations in elderly people

| Reference(s)         | Year   | Intervention                                      | Population | Outcomes | Effect size |
|----------------------|--------|---------------------------------------------------|------------|----------|-------------|
|                      |        |                                                   | Age        | Sex      |             |
| Banitalebi et al.    | 2018   | Resistance and endurance training                 | 67.3 ± 1.4 | Female   | ↑ 0.56      |
| Consid et al.        | 2016   | Endurance and strength training                    | 67 ± 3.3   | Male and female | ↑ 0.32 |
| DiPietro et al.      | 2008   | Aerobic training and strength training             | 77 ± 6     | Female   | ↓ 0.08      |
| Guia et al.          | 2019   | High intensity interval training                   | 62.3 ± 4.1 | Male     | ↓ 1.90      |
| Ha et al.            | 2018   | Combined resistance and aerobic training           | 73.0 ± 2.8 | Female   | ↓ 0.22      |
| Krishnan et al.      | 2014   | Aerobic and resistance training                    | 46.7 ± 3.3 | Female   | ↓ 0.79      |
| Micielska et al.     | 2019   | High-intensity circuit training                    | 45 ± 13    | Female   | ↓ 0.34      |
| Motiani et al.       | 2017   | Moderate-intensity continuous training and high-intensity training | 50.0 ± 3.6 | Male     | ↑ 0.22      |
| Nunes et al.         | 2019   | Resistance training                                | 64.2 ± 1   | Female   | ↓ 0.29      |
| Ogawa et al.         | 2010   | Resistance training                                | 85.0 ± 4.5 | Female   | ↓ 2.30      |
| Ramos et al.         | 2016   | Moderate-intensity continuous training and high-intensity training | 58 ± 7    | Male and female | ↓ 0.04 |
| Sellami et al.       | 2016   | High-intensity sprint training and strength training | 40.7 ± 1.8 | Male     | ↓ 0.60      |
| Søgaard et al.       | 2019   | High-intensity interval training                   | 63 ± 1     | Male and female | ↑ 0.32 |

↑ Indicates increase, ↓ indicates decrease

Table 7  Effects of training on insulin-like growth factor-1 (IGF-1) concentrations in elderly people

| Reference(s)         | Year   | Intervention                                      | Population | Outcomes | Effect size |
|----------------------|--------|---------------------------------------------------|------------|----------|-------------|
|                      |        |                                                   | Age        | Sex      |             |
| Banitalebi et al.    | 2018   | Resistance and endurance training                 | 67.3 ± 1.4 | Female   | ↑ 0.27      |
| Bennefoy et al.      | 1999   | Physical activity                                 | 69.7 ± 2.2 | Male and female | ↑ 0.46 |
| Berman et al.        | 1999   | Resistance training                                | 70.1 ± 1.0 | Male and female | ↑ 0.97 |
| Micielska et al.     | 2019   | High-intensity circuit training                    | 45 ± 13    | Female   | ↑ 0.32      |
| Nunes et al.         | 2019   | Resistance training                                | 64.2       | Female   | ↑ 0.26      |
| Ogawa et al.         | 2010   | Resistance training                                | 85.0 ± 4.5 | Female   | ↑ 1.06      |
| Praksch et al.       | 2019   | Home-based walking and aerobic training            | 67.4 ± 5   | Female   | ↑ 0.28      |
| Sato et al.          | 2014   | Resistance training                                | 67.2 ± 1.8 | Male     | ↑ 1.03      |
| Yamada et al.        | 2015   | Walking exercise and nutrition                     | 76.3 ± 5.9 | Male and female | ↑ 0.51 |

↑ Indicates increase, ↓ indicates decrease

Table 8  Effects of training on sex hormone-binding globulin (SHBG) concentrations in elderly people

| Reference(s)         | Year   | Intervention                                      | Population | Outcomes | Effect size |
|----------------------|--------|---------------------------------------------------|------------|----------|-------------|
|                      |        |                                                   | Age        | Sex      |             |
| Ahtiainen et al.     | 2015   | Heavy resistance exercise                         | 70 ± 2     | Male     | ↑ 0.25      |
| Glintborg et al.     | 2013   | Strength training                                 | 68         | Male     | ↑ 0.32      |
| Hayes et al.         | 2015   | Low- to medium- and high-intensity training       | 61 ± 5     | Male     | ↑ 0.38      |
| Hayes et al.         | 2017   | High-intensity training                           | 62 ± 2     | Male     | ↑ 0.43      |
| Kim et al.           | 2017   | Moderate physical activity                         | 51         | Male and female | ↑ 0.32 |
| Sellami et al.       | 2018   | Combined sprint and resistance training           | 40 ± 2     | Male     | ↑ 1.68      |

↑ Indicates increase, ↓ indicates decrease
Table 9  Effects of training on human growth hormone (hGH) concentrations in elderly people

| Reference(s)          | Intervention                             | Population | Outcomes | Effect size |
|-----------------------|------------------------------------------|------------|----------|-------------|
| Banitaleb et al. [70] | Resistance and endurance training         | 67.3 ± 1.4 | Female   | GH ↑        | 2.58        |
| Craig et al. [58]     | Progressive resistance training           | 62.8 ± 0.7 | Male     | GH ↑        | 0.34        |
| Im et al. [10]        | Yoga and Korean dance                     | 69.3 ± 2.9 | Female   | GH ↑        | 0.74        |
| Walker et al. [68]    | Resistance training                       | 63.7 ± 3   | Male     | GH ↑        | 0.29        |

↑ Indicates increase, ↓ indicates decrease

Table 10  Effects of training on dehydroepiandrosterone (DHEA) and dehydroepiandrosterone sulfate (DHEA-S) concentrations in elderly people

| Reference(s)          | Intervention                                      | Population | Outcomes | Effect size |
|-----------------------|---------------------------------------------------|------------|----------|-------------|
| Boxer et al. [83]     | DHEA supplements, aerobics and yoga               | 76.4 ± 6.2 | Female   | DHEA-S ↑   | 1.37        |
| Im et al. [10]        | Yoga and Korean dance                              | 69.3 ± 2.9 | Female   | DHEA-S ↑   | 0.98        |
| Kim et al. [56]       | Moderate physical activity                         | 51         | Male and female | DHEA-S ↑   | 0.37        |
| Krishnan et al. [65]  | Aerobic and resistance training                    | 46.7 ± 3.3 | Female   | DHEA-S ↑   | 0.41        |
| Nunes et al. [66]     | Resistance training                                | 64         | Female   | DHEA-S ↓   | 0.28        |
| Sato et al. [67]      | Resistance training                                | 67.2 ± 1.8 | Male     | DHEA-S ↑   | 1.71        |
| Yamada et al. [79]    | Walking exercise and nutrition                     | 76.3 ± 5.9 | Male and female | DHEA-S ↑   | 0.55        |

↑ Indicates increase, ↓ indicates decrease

**Effects of exercise training observed in advanced age**

Ostensibly anabolic hormones: \( \text{testosterone, IGF-1, hGH, insulin, DHEA-S} \)

Binding protein: \( \text{SHBG} \)

Ostensibly catabolic hormones: \( \text{Corticosteroids} \)

Typical endocrine effects of advanced age

Andropause: \( \text{testosterone, DHEA-S} \)

Reduced free testosterone: \( \text{SHBG} \)

Somatopause: \( \text{IGF-1, hGH} \)

Hyperinsulinemia: \( \text{insulin} \)

Hypercortisolema: \( \text{corticosteroids} \)

Fig. 2  Top: Summary of the main effects of exercise on hormones discussed in this review. Bottom: Summary of the main effects of ageing on hormones discussed in this review. IGF-1 insulin-like growth factor-1, hGH human growth hormone, DHEA-S dehydroepiandrosterone sulfate, SHBG sex hormone-binding globulin. \( \text{↑} \) indicates increase; \( \text{↓} \) indicates decrease
a small decrease in cortisol to a very large increase, indicating an inconsistency in findings. Cortisol, corticosterone, cortisone and 11-deoxycortisol are key biomarkers of stress, particularly of acute stress [68]. Exercise training reduces stress in the elderly and often decreases basal cortisol and raises testosterone levels [58]. Recent studies report that post-training basal blood cortisol levels are decreased relative to non-exercise populations, and that exercise-induced changes in cortisol are unrelated to the volume, type and duration of exercise [68, 69]. A study by Hayes et al. [63] reported no improvements in blood cortisol levels after 12 weeks of training (of which 6 weeks was HIIT), although other reports indicated that increases in blood cortisol levels are not related to the type of exercise. It is possible that a single exercise bout may not be sufficient to cause persistent changes in adrenal function; however, benefits are likely if the exercise intensity is sufficient (~60% maximal oxygen uptake), which is common in younger adults [15]. Another possibility is that age-related changes in the hypothalamus-pituitary axis may alter responses to exercise [14].

4.3 Effect of Exercise on DHEA and DHEA-S

Small to very large increases of DHEA and DHEA-S post-training were generally observed in our analysis, although the number of studies was relatively small. Men’s DHEA-S responses were also greater than those of women [55]. DHEA levels decreased around 65 years of age and were associated with reduced muscle strength in males but not in females [81]. However, a significant decline in the circulating androgen DHEA-S between the ages 20 and 50 years was associated with the normal ageing process for women [64]. We observed that exercise tends to maintain blood levels of DHEA in both men and women. Even a single bout of exercise has demonstrated immediate increases in circulating androgen levels (testosterone and DHEA-S) [64]. DHEA hormonal levels are in general positively correlated with normal physical activity, involvement in sport and aerobic ability [93]. The effects of exercise training on DHEA-S levels differ in males and females [55]. Several studies have shown that serum DHEA levels in older adults are increased significantly by exercise training [66, 78]. Recent evidence suggests that increased levels of DHEA-S during the menopausal transition can double cardiovascular disease risk and diabetes mellitus [10].

4.4 Effect of Exercise on Insulin

We found that exercise training reduces blood insulin levels in older adults in most studies, with four studies showing small to moderate increases [55, 70, 76, 77]. Effect sizes ranged from small to very large, with some variability in the findings. These divergent effects did not seem to be related to study duration, as those studies with the largest positive effects [73, 91] were only 12 weeks in duration. This corroborates a recent study [94] in which no changes were noted to insulin levels measured after 12 weeks of training in lifelong exercisers or lifelong sedentary older adults. Small to moderate effects were observed in the previously sedentary group only, suggesting that participant selection may have contributed to the variability we found. Insulin sensitivity decreases with age and can lead to insulin resistance and type 2 diabetes mellitus [70, 75]. Skeletal muscle dysfunction and disuse associated with ageing is a primary cause of impaired glucose absorption and reduced mitochondrial oxidation [75]. Skeletal muscles are responsible for >60% of glucose metabolism [72], and thus exercise in older adults is an important regulator of glucose metabolism. HIIT improves insulin sensitivity, body composition and cardiovascular health [76], and several studies suggest the increase in insulin sensitivity due to exercise training is directly proportional to exercise intensity and volume [70, 71], although there is also evidence that combined training may be more efficacious than one form of training alone [64, 69–71].

4.5 Effect of Exercise on IGF-1

Levels of IGF-1 were ubiquitously increased in the all the studies we analysed, with small to large effect sizes being evident. IGF-1 plays an important role in muscle development and insulin sensitivity [65], and changes in IGF-1 are correlated with cardiovascular disease risk and mortality [77]. IGF-1 levels decrease during ageing (i.e., the menopause), but several exercise types can affect the synthesis of IGF-1 [65, 66, 72, 77]. Increased IGF-1 levels cause downstream improvements in insulin activity [65, 66, 77]. Resistance training reportedly causes greater increases in IGF-1 relative to endurance training [65, 69]. Combined training with different exercise sequences did not affect IGF-1 [69]. When comparing concurrent training with interval training, concurrent training produced greater increases in IGF-1 levels [69]. Yet, high-intensity circuit training also produced significant elevations of IGF-1 that were accompanied by improvements in the homeostatic model assessment index of insulin resistance (HOMA1-IR) [72]. One important issue to consider from these data is the interpretation of increased IGF-1 levels. For example, Herbert et al. [33] reported increased IGF-1 following HIIT in previously sedentary older masters athletes, who had higher levels of IGF-1 than sedentary individuals, causing these authors to propose increased IGF-1 in older men was a positive physiological adaptation. Conversely, Hayes et al. [95] concluded IGF-1 decreases were a positive physiological adaptation following resistance training. These authors hypothesized that IGF-1 entered muscle tissue to exert downstream hypertrophic effects during periods of muscle building (i.e., anabolism).
Muscle hypertrophy is not the only response to perturbations in IGF-1, with other effects of IGF-1 possible in participants who exercise.

### 4.6 Effect of Exercise on SHBG

Our analysis indicates that levels of SHBG in older adults were universally increased by exercise. This glycoprotein binds to androgens and oestrogens and its levels increase with age whilst testosterone decreases, resulting in lower levels of bioavailable and free testosterone available for biological effects following tissue uptake. Therefore, it is imperative to measure both SHBG and testosterone levels to obtain a better understanding of androgenic status. In this context, Hayes et al. [63] previously reported increases in total testosterone and SHBG levels, with no alterations in free testosterone levels [62]. There were larger increases in total testosterone SHBG when HIIT was used as the exercise protocol, suggesting increases in free testosterone [63]. Therefore, it is important to distinguish which hormone fraction is being measured in such studies. Low SHBG suggests a high androgenic nature in women, which is inversely related with adiposity and SHBG levels [55].

### 4.7 Effect of Exercise on Human Growth Hormone

We found only four studies that measured hGH, all which reported increases in hGH having effect sizes from small to very large [10, 58, 68, 70]. One possible reason for the limited number of studies measuring hGH may be its short biological half-life, making it more pragmatic to measure IGF-1, the main downstream protein of hGH secretion [68]. When comparing other forms of exercise, resistance training causes the largest increases in hGH levels in older adults [67]. Ageing accelerates the reduction of hGH secretion in both sexes, with females experiencing steeper declines than males [67, 69, 77]. Combined exercise programs such as resistance and endurance increase hGH levels [69].

### 5 Conclusion

In conclusion, exercise increases the levels of anabolic hormones in older adults, although the clinical significance of these alterations remains uncertain. It is apparent that exercise exerts anti-ageing effects on several physiological systems, but whether these effects are mediated by the endocrine system is unclear at this time. Nonetheless, we recommend that exercise should be considered as a first-line treatment for endocrine dysfunction as it improves several changes of the hormonal regulation that occur with ageing. Future investigations may wish to address the effects of exercise on hormonal concentrations in middle-aged individuals as this is typically where age-associated hormonal milieu alterations may begin to manifest. In the present review, regretfully we found that too few original articles were conducted in participants aged 40–60 years, so additional articles in this age category would have allowed us to examine age differences and would have permitted practical applications for each age category.

**Data Availability Statement** All data supporting the findings of this study are available in this published article.

**Declarations**

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**Author Contributions** Hassane Zouhal was involved in the conceptualization of the study, data analysis and writing the manuscript. Ayyappan Jayavel, Kamalananthan Parasuraman, Lawrence D. Hayes, Claire Tourny, Fatma Rhibi, Ismail Laher, Abderraouf Ben Abderrahman and Anthony C. Hackney were involved in the data assessment, data analysis and writing the manuscript. All authors approved the final version of the manuscript.

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