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# Diurnal variation in maximum endurance and maximum strength performance: a systematic review and meta-analysis

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## MATERIALS AND METHODS

### Search strings

The following search strings were used for the different databases. The initial search was performed on November 6, 2018 and an updated literature search was performed on November 17, 2020. The updated search was performed with the identical search strings for all three databases, but the year of publication was limited to 2017 to 2020. The publication year 2017 was chosen to ensure an overlap of two years between the initial and updated search.

***Pubmed:*** ((time-of-day[tiab] OR times-of-day[tiab] OR time-of-the-day[tiab] OR times-of-the-day[tiab] OR daytimes[tiab] OR daytime[tiab] OR circadian rhythm[MeSH] OR Circadian rhythm*[tiab] OR diurnal variation[tiab] OR intra-day[tiab] OR inter-day[tiab] OR intraday[tiab] OR interday[tiab] OR circadian variation[tiab] OR circadian phenotype[tiab] OR morning type*[tiab] OR evening type*[tiab] OR periodicity[tiab] OR chronotype[tiab] OR temporal specificity[tiab] OR biological clock[tiab] OR circadian clock[tiab] OR circadian clocks[tiab] OR circadian cycle[tiab] OR circadian fluctuation[tiab] OR circadian periodicity[tiab] OR circadian rhythmicity[tiab] OR day night rhythm[tiab] OR diurnal cycle[tiab] OR diurnal fluctuation[tiab] OR diurnal pattern[tiab] OR diurnal rhythm[tiab] OR diurnal rhythmicity[tiab] OR nychtohemeral[tiab] OR phenotype variance[tiab] OR phenotype variation[tiab] OR biologic clock[tiab] OR biologic rhythm[tiab] OR biological clocks[tiab] OR biorhythm[tiab]) AND (athletic performance[MeSH] OR muscle strength[MeSH] OR

muscle fatigue[MeSH] OR oxygen consumption[MeSH] OR torque[MeSH] OR exercise test[MeSH] OR athletic performance[tiab] OR physical performance[tiab] OR muscle strength[tiab] OR resistance performance[tiab] OR muscle fatigue[tiab] OR muscular fatigue[tiab] OR oxygen consumption[tiab] OR power output[tiab] OR maximal power[tiab] OR VO2max[tiab] OR VO2peak[tiab] OR endurance[tiab] OR endurance performance[tiab] OR torque[tiab] OR torques[tiab] OR 1-RM[tiab] OR peak torque[tiab] OR exercise test[tiab] OR exercise tests[tiab] OR Arm Ergometry Test[tiab] OR Arm Ergometry Tests[tiab] OR Bicycle Ergometry Test[tiab] OR Bicycle Ergometry Tests[tiab] OR Fitness Testing[tiab] OR Fitness Testings[tiab] OR Fitness Test[tiab] OR Fitness Tests[tiab] OR Step Test[tiab] OR Step Tests[tiab] OR Ramp Test[tiab] OR Ramp Tests[tiab] OR Stress Test[tiab] OR Stress Tests[tiab] OR Treadmill Test[tiab] OR Treadmill Tests[tiab] OR Cardiopulmonary Exercise Test[tiab] OR Cardiopulmonary Exercise Tests[tiab] OR Wingate[tiab] OR dynamic strength[tiab] OR muscle force[tiab] OR muscle power[tiab] OR muscular force[tiab] OR muscular power[tiab] OR muscular strength[tiab] OR muscle strengthening[tiab] OR myofunctional therapy[tiab] OR resistance exercise[tiab] OR strength training[tiab] OR weight bearing exercise[tiab] OR endurance exercise[tiab] OR load carrying[tiab] OR weight-bearing[tiab] OR endurance shuttle walk testing[tiab] OR effort test[tiab] OR exercise testing[tiab] OR torsional moment[tiab] OR torsional moments[tiab] OR turning force[tiab] OR O2 consumption[tiab] OR o2 uptake[tiab] OR oxygen demand[tiab] OR oxygen intake[tiab] OR oxygen requirement[tiab] OR oxygen uptake[tiab] OR oxygen utilization[tiab] OR treadmill running[tiab] OR treadmill testing[tiab] OR ergometer testing[tiab] OR endurance testing[tiab] OR strength testing[tiab]) ) NOT ("animals"[MeSH Terms] NOT "humans"[MeSH Terms])

***Embase:*** ('circadian rhythm'/exp OR 'circadian rhythm':ti,ab OR 'time of day'/exp OR 'time-of-day':ti,ab OR 'times-of-day':ti,ab OR 'time-of-the-day':ti,ab OR 'times-of-the-day':ti,ab OR 'diurnal variation':ti,ab OR 'intra-day':ti,ab OR 'inter-day':ti,ab OR intraday:ti,ab OR interday:ti,ab OR daytimes:ti,ab OR daytime:ti,ab OR 'phenotypic variation'/exp OR 'phenotypic variation':ti,ab OR 'circadian phenotype':ti,ab OR (('morning'/exp OR morning:ti,ab) AND type*:ti,ab) OR (('evening'/exp OR evening:ti,ab) AND type*:ti,ab) OR 'periodicity'/exp OR periodicity:ti,ab OR 'chronotype'/exp OR chronotype:ti,ab OR 'temporal specificity':ti,ab OR (temporal:ti,ab AND ('specificity'/exp OR specificity:ti,ab)) OR 'biological rhythm'/exp OR 'biological rhythm':ti,ab OR 'circadian rhythms':ti,ab OR 'circadian clock':ti,ab OR 'circadian clocks':ti,ab OR 'circadian cycle':ti,ab OR 'circadian fluctuation':ti,ab OR 'circadian periodicity':ti,ab OR 'circadian rhythmicity':ti,ab OR 'circadian variation':ti,ab OR 'day night rhythm':ti,ab OR 'diurnal cycle':ti,ab OR 'diurnal fluctuation':ti,ab OR 'diurnal pattern':ti,ab OR 'diurnal rhythm':ti,ab OR 'diurnal rhythmicity':ti,ab OR 'nychtohemeral':ti,ab OR 'phenotype variance':ti,ab OR 'phenotype variation':ti,ab OR 'biologic clock':ti,ab OR 'biologic rhythm':ti,ab OR 'biological clocks':ti,ab OR 'biorhythm':ti,ab ) AND ('physical performance'/exp OR 'physical performance':ti,ab OR 'fitness'/exp OR fitness:ti,ab OR 'athletic performance'/exp OR 'athletic performance':ti,ab OR 'muscle strength'/exp OR 'muscle strength':ti,ab OR 'muscle training'/exp OR 'muscle training':ti,ab OR 'muscle fatigue'/exp OR 'muscle fatigue':ti,ab OR 'resistance training'/exp OR 'resistance training':ti,ab OR 'strengthening exercise'/exp OR 'strengthening exercise':ti,ab OR 'endurance training'/exp OR 'endurance training':ti,ab OR 'endurance sport'/exp OR 'endurance sport':ti,ab OR 'weight bearing'/exp OR 'weight bearing':ti,ab OR 'endurance'/exp OR endurance:ti,ab OR 'endurance performance':ti,ab OR 'endurance shuttle walk test'/exp OR 'endurance shuttle walk test':ti,ab OR 'exercise test'/exp OR 'exercise test':ti,ab OR 'power output'/exp OR 'power output':ti,ab OR 'torque'/exp OR torque:ti,ab OR 'one repetition maximum test'/exp OR 'one repetition maximum test':ti,ab OR 'peak torque'/exp OR 'peak torque':ti,ab OR 'oxygen consumption'/exp

OR 'oxygen consumption':ti,ab OR 'maximal oxygen uptake'/exp OR 'maximal oxygen uptake':ti,ab OR 'maximal oxygen consumption'/exp OR 'maximal oxygen consumption':ti,ab OR 'step test'/exp OR 'step test':ti,ab OR 'treadmill test'/exp OR 'treadmill test':ti,ab OR 'ergometry'/exp OR ergometry:ti,ab OR 'treadmill exercise'/exp OR 'treadmill exercise':ti,ab OR 'wingate test'/exp OR 'wingate test':ti,ab OR 'wingate anaerobic test'/exp OR 'wingate anaerobic test':ti,ab OR 'cardiorespiratory fitness'/exp OR 'cardiorespiratory fitness':ti,ab OR 'cardiorespiratory endurance'/exp OR 'cardiorespiratory endurance':ti,ab OR jump:ti,ab OR 'cardiopulmonary fitness'/exp OR 'cardiopulmonary fitness':ti,ab OR 'cardiopulmonary exercise test'/exp OR 'cardiopulmonary exercise test':ti,ab OR 'cardiopulmonary exercise testing'/exp OR 'dynamic strength':ti,ab OR 'muscle force':ti,ab OR 'muscle power':ti,ab OR 'muscular force':ti,ab OR 'muscular power':ti,ab OR 'muscular strength':ti,ab OR 'muscle strengthening':ti,ab OR 'myofunctional therapy':ti,ab OR 'resistance exercise':ti,ab OR 'resistance exercise training':ti,ab OR 'strength training':ti,ab OR 'weight bearing exercise':ti,ab OR 'endurance exercise':ti,ab OR 'load carrying':ti,ab OR 'weight-bearing':ti,ab OR 'effort test':ti,ab OR 'exercise testing':ti,ab OR 'stress test':ti,ab OR 'torsional moment':ti,ab OR 'torsional moments':ti,ab OR 'O2 consumption':ti,ab OR 'O2 uptake':ti,ab OR 'oxygen demand':ti,ab OR 'oxygen intake':ti,ab OR 'oxygen requirement':ti,ab OR 'oxygen uptake':ti,ab OR 'oxygen utilization':ti,ab OR 'treadmill running':ti,ab OR 'turning force':ti,ab OR 'treadmill testing':ti,ab OR 'ergometer testing':ti,ab OR 'endurance testing':ti,ab OR 'strength testing':ti,ab OR 'muscular fatigue':ti,ab OR 'muscle force':ti,ab OR 'muscular force':ti,ab OR 'muscular strength':ti,ab OR 'maximal power':ti,ab OR 'VO2max':ti,ab OR 'VO2peak':ti,ab OR '1-RM':ti,ab OR 'Ramp Test':ti,ab OR 'Ramp Tests':ti,ab) NOT ('animals'/exp NOT 'humans'/exp)

***Web of Science:*** (“time-of-day” OR “time-of-the-day” OR chronobiological OR “twenty-four hour” OR diurnal OR circadian OR “intra-day” OR periodicity OR “biological clock” OR “intra-day” OR “inter-day” OR intraday OR interday OR chronotype OR “circadian clock” OR “circadian clocks” OR “circadian rhythmicity” OR “circadian variation” OR “diurnal pattern” OR “diurnal rhythm” OR “biologic rhythm” OR “biological clocks” OR “temporal specificity” OR “day night rhythm” OR biorhythm) AND (“athletic performance” OR “sports performance” OR “muscle strength” OR “muscular fatigue” OR “muscle force” OR “muscular force” OR “muscular strength” OR “strength performance” OR “resistance performance” OR “physical endurance” OR “endurance performance” OR “physical performance” OR “muscle fatigue” OR “resistance training” OR “strength training” OR ((strengthening OR exercise) AND program*) OR “oxygen consumption” OR “weight-bearing” OR “exercise test*” OR “power output” OR “maximal power” OR “1-RM” OR “peak torque” OR “VO2max” OR “VO2peak” OR “step test*” OR “ramp test*” OR “treadmill test*” OR “ergometry test*” OR “wingate test” OR “fitness testing” OR “physical fitness test” OR “cardiorespiratory fitness” OR jump OR “Fitness Test” OR “Fitness tests” OR “Step Test” OR “Step Tests” OR “Ramp Test” OR “Ramp Tests” OR “Stress Test” OR “Stress Tests” OR “Cardiopulmonary Exercise Test” OR “Cardiopulmonary Exercise Tests” OR “Wingate” OR “dynamic strength” OR “muscle force” OR “muscle power” OR “muscular force” OR “muscular power” OR “muscular strength” OR “muscle strengthening” OR “endurance exercise” OR “O2 uptake” OR “oxygen uptake” OR “treadmill running” OR “treadmill testing” OR “ergometer testing” OR “endurance testing” OR “strength testing” OR torque OR “muscular fatigue” OR endurance OR “myofunctional therapy” OR “resistance exercise” OR “load carrying” OR “oxygen demand” OR “oxygen intake” OR “oxygen utilization”)

## Synthesising results

### *Initially planned meta-analysis*

A meta-analysis of results was aimed for the four different categories (1) endurance exercise tests, (2) 30-s Wingate tests, (3) jump height tests, and (4) maximum handgrip strength. Studies measuring one of the following outcomes were eligible for inclusion in the initially intended meta-analysis: (1) $VO_2$max (mL/kg/min), (2) mean power output (W/kg) from 30s Wingate test, (3) jump height (cm) from countermovement jump, and (4) peak force (N) from maximum handgrip strength, respectively. In each of the four categories 7, 7, 5, and 14 studies were eligible for inclusion. The rationale for choosing these four outcomes as summary measures were: $VO_2$max represents the gold standard for cardiorespiratory fitness. 30-s Wingate test is a highly standardized test and in addition has a fix duration as compared to time trials, repeated sprint tests, or forced velocity tests which can all differ in test duration across studies. Hence, mean power output from 30-s Wingate test was chosen as an outcome measure to synthesize the results. Peak power output was not considered, because the analysed epochs to define peak power differed from 1 to 5 seconds between studies. Countermovement jump was chosen because it is better standardized as compared to squat jump. In detail, studies testing squat jump differed in load (i.e., loaded versus unloaded squat jump) and in starting position (i.e., different knee angles). For isometric or isokinetic strength testing different muscle groups were tested in different positions, and different velocities were used in the isokinetic tests. These differences in test standardization and outcome measures cause a large heterogeneity. Furthermore, it is unclear if the magnitude in diurnal variations differ between muscle groups, and if the different muscle groups display their peak/nadir performance at different times of the day within the same subject. In addition, the number of studies per muscle group was limited, with 11 out of 13 muscle groups providing data for $\leq 3$ studies. Therefore, the handgrip strength test was chosen to synthesize the results as this measurement is highly standardized between studies.

To contact the corresponding authors, details of the full-text articles were used. If no contact information was available the following methods were used in this particular order to receive contact information: (1) other publications of the same author were searched on Pubmed for contact details, (2) research gate was searched, (3) the institution's homepages was searched and (4) a google search for contact details was done. If a corresponding author's email was not available, not valid anymore or the author was deceased or retired one further co-author was contacted. Thereby, the latter four-step process was repeated for the next author to gather

contact information. Contact details from ten studies could not be gathered. The remaining corresponding authors were contacted via email on December 14, 2020 and send an excel-sheet which was individualized for each study regarding the number of participants, outcomes, and measured time points. This sheet also calculated all required data automatically to reduce the burden for the corresponding authors and increase the response rate. Reminders were sent after two weeks on December 28, 2020.

Data on effect size and 95% CI were only available from two studies. This did not allow us to perform the originally planned meta-analysis which requires the mean and standard deviation at the time of the day with the highest and lowest performance, as well as the within-subject correlation. We were still able to synthesize the reported data graphically (see Figure 2). In detail, in Figure 2A, time trials and shuttle-run tests were also included in addition to studies measuring $VO_2$max. In Figure 2D, studies performing unloaded squat jumps were also included in addition to studies performing countermovement jumps. For those studies reporting the results independently for different chronotypes (i.e., Hill 2020, Facer-Childs et al., 2015, Facer-Childs et al., 2018) or different fitness levels (i.e., Atkinson 1993), the data was pooled for the purpose of creating Figure 2. Lydann et al. (1971) tested two groups but only one was reported in the publication, therefore the data of the reported group was used. The study Hill (1991) was excluded, because the respective data for the outcome was not reported in the study. The study Sargent (2010) did not report the actual times of the day the tests were performed and was therefore excluded from Figure 2. The study Jasper (2009) was excluded, because a constant routine protocol with 40 hours of sleep deprivation was performed. The study by Souissi (2010) is the only study that included adolescents and it is represented in Figure 2B, 2C and 2D, because it measured multiple outcomes. The online tool web plot digitizer was used for the following studies: Facer-Childs (2015), Faria (1982), Ilmarinen (1975), Melhim (1983), Souissi (2010), Atkinson (1993), Facer-Childs (2018), Ghattassi (2016), Ilmarinen (1980), Lyddan (1971), and Teo (2011).

***Performed meta-analysis***

For the meta-analysis we performed we chose the measurements at 8:00 – 10:00 as the comparison value here, because: 1) the measurements in this time window rarely were the peak performance, but rather often to be the lowest performance and 2) all, except two, studies included in the current meta-analysis had a single time-point measurement between 08:00 – 10:00. Those two studies (i.e., Illmarinen et al., 1975 and Illmarinen et al., 1980) both had a high risk of bias and a small sample sizes of four and six participants, respectively. Hence, the

exclusion of these studies is not likely to influence the overall result of the meta-analysis. In this way, it allows us to include most studies in the meta-analysis, while minimizing the chances to underestimate the magnitude of diurnal variation.

The formula used to calculate Cohen's *d* for individual studies is:

$$Cohen's\ d = \frac{Mean_1 - Mean_2}{\sqrt{SD_1^2 + SD_2^2 - 2 \times r \times SD_1 \times SD_2}} \times \sqrt{2 \times (1 - r)},$$

where $Mean_1$ and $Mean_2$ are the group averages of peak performance and performance at 8:00 – 10:00, $SD_1$ and $SD_2$ are the standard deviations of peak performance and performance at 8:00 – 10:00, and *r* is the correlation between within-participant measurements. Since the true *r* is unknown for each study, we computed two sets of Cohen's *d* with the assumption that *r*=0.5 (see supplemental Figure S1) and *r*=0.8 (see Figure 3), respectively. Notably, the correlation of the study where *r* is known was between 0.7 and 0.8 for isometric arm strength, isometric leg strength, and jump height (Knaier et al. 2019). Besides the studies by Ilmarinen 1975 and 1980, two further studies (i.e., Atkinson 1993 and Lyddan 1971) were excluded from the meta-analysis, because no measure of variation for the relevant outcomes were reported. The studies were weighted by sample size, i.e., a study with twice the sample size as compared to another study was weighted as twice the weight of the other study.. No sensitivity or sub-group analyses were intended or performed for sex, because none of the studies reported group means by sex, which made it impossible to extract effect size by sex.

**Table S1: Criteria for risk of bias assessment**

| | Low risk | Unclear | High risk |
|---|---|---|---|
| Selection bias | Sex (%) AND mean age including standard deviation AND any information regarding level of fitness reported | Not applicable | Any of the three criteria has not been reported |
| Detection bias | | | |
| Gold standard | $VO_2$max/$VO_2$-deficit measured for endurance performance OR use of isokinetic dynamometer for strength performance | Not reported | Gold standard not used (e.g. shuttle-run test, Wingate test without measurement of $VO_2$-deficit or 1-RM) |
| Constant conditions | Equal preparation (i.e. warm-up, preparation before test) AND equal external factors (i.e. room temperature, humidity) | Not reported | Tests performed under different preparation or external factors (e.g. free choice of warm-up duration or outdoor tests) |
| Confounding | | | |
| Regeneration | Regeneration phase ≥ 6 hours (except for handgrip strength test) | Not reported | Regeneration phase < 6 hours (except for handgrip strength test) |
| Familiarization | Minimum of one familiarization trial was performed | Not reported | Statement that no familiarization trial was performed |
| Sequence | Tests at different times of the day were performed in randomized sequence | Not reported | Tests were performed in the same sequence |
| Sleep/Physical activity | Instructions were given to have normal sleeping routine and restrain from intense physical activity OR sleep and physical activity were controlled by questionnaires or accelerometers | Not reported | Statement that participants did not have to keep normal/regular sleep routine |
| Reporting Bias | | | |
| Effect Size | Effect sizes OR mean differences including 95% confidence intervals are reported | Not applicable | No effect sizes OR no 95% confidence intervals are reported |
| All absolute data | Main data are reported as absolute values AND data for all maximum performance related outcomes are reported | Not applicable | Only %-values are reported OR only selective outcomes are reported |
| Times of day | Data for all times of the day that were tested are reported | Not applicable | Only data from some time points (e.g. peak) are reported. |

**Table S2: Diurnal variation in maximum endurance and maximum strength performance.**

| First-author (Year) | N (Sex) Age (Years) Fitness Level | Test Times | Exercise Tests (Protocol) [Device] | Outcomes (Unit) | Time Peak / Nadir | Result Peak / Nadir (p-value) |
|---|---|---|---|---|---|---|
| **Endurance exercise tests** | | | | | | |
| Deschenes (1998b) | 10 (m)<br>21.1 ± 3.0<br>active | 08:00, 12:00, 16:00, 20:00 | incremental test (30 W/ 2 min) [cycle ergometer] | $VO_2$max (mL/kg/min) | 20:00 / 08:00 | 56.9 ± 10.2 / 52.0 ± 7.0 (> 0.05) |
| Dolton (1997) | 7 (m)<br>22.3 ± 4.9<br>trained | 09:00, 15:00, 21:00 | 15-min time trial [cycle ergometer] | total work (kJ) | 09:00 / 15:00 | 278.3 ± 9.8$^{SEM}$ / 276.5 ± 9.6$^{SEM}$ (> 0.05) |
| Facer-Childs (2015) | 20 (not reported)<br>20.4*<br>trained hockey | 07:00, 10:00, 13:00, 16:00, 19:00, 22:00 | 20-m shuttle run | distance (m) | 16:00# / 07:00# | absolute values not reported |
| Faria (1982) | 15 (m) / 16 (f)<br>23.3 ± 0.7$^{SE}$<br>not reported | every 2 hrs over a 24 hrs period | incremental test (m/f: 11.3/ 8.9 km/h, elevation: +2.5%/ 2 min) [treadmill] | $VO_2$max (mL/kg/min) | 24:00 / 02:00 | 48.8# ± 1.6$^{SE}$# / 46.3# ± 0.9$^{SE}$# (> 0.05) |
| Ilmarinen (1975) | 6 (m)<br>16.3 ± 1.5<br>trained cyclists | 07:00, 11:00, 15:00, 19:00, 23:00, 03:00 | 6-min 140-160 bpm, 3-min rest, 6-min 160-180 bpm, 3-min rest, 3-min 170-190 bpm, 30 s maximum rpm with same load [cycle ergometer] | $VO_2$max (L/min) | 15:00 / 23:00 | 5.03# ± 0.10# / 4.77# ± 0.17# (0.023) |
| Knaier (2019a) | 10 (m) / 7 (f)<br>28 ± 5.1<br>trained | 07:00, 10:00, 13:00, 16:00, 19:00, 21:00 | incremental test (25 W/min males, 20 W/min females) [cycle ergometer] | VO2max (L/min)<br>VO2max (mL/kg/min) | 19:00 / 13:00<br>19:00 / 16:00 | 3.84 ± 0.6 / 3.75 ± 0.67 (> 0.05)<br>56.0 ± 6.0 / 54.3 ± 6.4 (> 0.05) |

| | | | | | | |
|---|---|---|---|---|---|---|
| Reilly (1990) | 15 (m)<br>26.2 ± 3.9<br>trained | 02:00, 06:00, 10:00, 14:00, 18:00, 22:00 | Step-incremental test ( 5-min 82 W, 5-min 147, increment of 33 W / 2 min) [cycle ergometer] | $VO_2$max (mL/kg/min)<br><br>time to exhaustion (min) | 10:00 / 02:00<br><br>22:00 / 06:00 | 53.0 ± 6.2 / 51.1 ± 5.9 (≥ 0.05)<br><br>20.0 ± 0.1 / 19.6 ± 2.1 (≥ 0.05) |
| Reilly (1984) | 10 (m)<br>range: 19-22<br>athletes | 03:00, 09:00, 15:00, 21:00 | Incremental/time to exhaustion (5 min 150 W, increment 30 W / 2 min until 400W, unitl exhaustino) [cycle ergometer] | time to exhaustion (min) | 15:00 / 03:00 | 35.2 ± 13.9 / 32.9 ± 8.2 (≥ 0.05) |
| Zadow (2018) | 15 (m)<br>41.5 ± 10.0<br>trained cyclists | 08:30, 11:30, 14:30, 17:30, 20:30 | 4-km cycling time trial [bicycle fitted in an ergometer stand] | $VO_2$max (% maximum)<br>mean power (W)<br>time trial time (s) | 17:30 / 20:30<br>11:30 / 08:30<br>14:30 / 08:30 | 87.3 ± 8.4 / 82.5 ± 8.4 **(≤ 0.05)**<br>329.5 ± 34.0 / 324.5 ± 34.4 (≥ 0.05)<br>424 ± 44 / 436 ± 49 (≥ 0.05) |
| Zadow (2020) | 19 (m)<br>39.0 ± 10.7<br>trained cyclists | 08:30, 11:30, 14:30, 17:30, 20:30 | 4-km cycling time trial [bicycle fitted in an ergometer stand] | $VO_2$max (% maximum)<br>mean power (W)<br>time trial time (s) | 17:30 / 20:30<br>11:30 / 08:30<br>11:30 / 20:30 | 86.4 ± 8.0 / 82.3 ± 8.1 (≥ 0.05)<br>339.8 ± 37.2 / 333.0 ± 38.9 (≥ 0.05)<br>416.3 ± 31.2 / 421.5 ± 58.8 (≥ 0.05) |
| **Short-duration time trials, force velocity test, 30-s Wingate test, and sprint test** | | | | | | |
| Baxter (1983) | 4 (m) / 10 (f)<br>14.7*<br>trained swimmers | 06:30, 09:00, 13:30, 17:00, 22:00 | 100 m and 400 m time trial (front crawl swim) | duration 100 m (s)<br><br>duration 400 m (s) | 22:00 / 06:30<br><br>22:00 / 06:30 | 72.6 ± 10.6 / 75.3 ±10.8 **(≤ 0.05)**<br><br>329.1 ± 23.8 / 337.7 ± 24.2 **(≤ 0.05)** |
| Bernard (1998) | 23 (m)<br>23.0 ± 3.0<br>not reported | 09:00, 14:00, 18:00 | force velocity test (repetitive 6 - 8 s sprints with 5-min recovery) [cycle ergoemeter]<br>50-m running | maximal power (W/kg)<br>maximal power (W)<br>peak velocity (m/s) | 14:00 / 09:00<br>14:00 / 09:00<br>18:00 / 09:00 | 14.8 ± 2.6 / 14.3 ± 2.4 (< 0.01)<br>1077 ± 224 / 1049 ± 216 (< 0.05)<br>9.40 ± 0.67 / 9.26 ± 0.7 (0.0544) |
| Chtourou (2013) | 10 (m)<br>18.2 ± 1.4<br>trained judokas | 09:00, 12:30, 16:00 | 30s wingate test (tqurque factor 87g/ kg) [cycle ergometer] | peak power (W/kg)<br><br>mean power (W/kg) | 16:00 / 09:00<br><br>16:00 / 09:00 | 11.6 ± 1.5 / 11.3 ± 1.4 **(≤ 0.05)**<br><br>8.3 ± 0.7 / 8.0 ± 0.8 **(≤ 0.05)** |

| | | | | | | |
|---|---|---|---|---|---|---|
| Deschodt (2004) | 5 (m) / 6 (f)<br>19.0 ± 1.3<br>trained swimmers | 08:00, 13:00, 18:00 | force velocity test (20 pedal revolitions sprints at friction-loads30 g/kg and 60 g/kg) [cylce ergometer] | peak power (W)<br>total work (kJ)<br>30g/kg<br>total work (kJ)<br>60g/kg | 18:00 / 08:00<br>13:00 / 08:00<br>18:00 / 08:00 | 802 ± 354 / 739 ± 313 (< 0.01)<br>12.54 ± 2.48 / 11.97 ± 2.32 (<0.01)<br>14.79 ± 3.17 / 14.25 ± 3.12 (<0.01) |
| Falgairette (2003) | 9 (m)<br>23.0 ± 2.0<br>trained | 09:00, 14:00, 18:00 | force velocity test (repetitive 7 s sprints against increasing breaking forces (3, 5, 7, 9, 10 and 11 kg; 5 min recovery) [cycle ergoemeter] | peak power (W) | 14:00 / 09:00 | 1097 ± 140 / 1090 ± 152 (≥ 0.05) |
| Hill (1991) | 6 (m)<br>22.0 ± 3.0<br>active | 03:00, 09:00, 15:00, 21:00 | 30s wingate test (resistance 5.5 kg) [cycle ergoemeter] | peak power (W)<br><br>mean Power (W) | 21:00 / 03:00<br><br>21:00 / 03:00 | absolute values not reported<br><br>absolute values not reported |
| Hill (2020) | 8 (m) 6 (f)<br>22 ± 2<br>active | 08:00, 14:00, 20:00 | 30s wingate test | peak power (W/kg)<br><br>mean power (W/kg) | 20:00/ 08:00<br><br>20:00/ 08:00 | 9.1 ± 1.5 / 8.5 ± 1.4 (= 0.01)<br><br>7.35 ± 1.25 / 6.9 ± 1.15 (< 0.01) |
| Javierre (1996) | 8 (m)<br>21.3 ± 3.9<br>trained sprinters | 09:00, 11:00, 13:00, 15:00, 17:00, 19:00, 21:00, 23:00 | 80m sprint | time (s) | 19:00/ 23:00 | 9.55 / 10.00 (p-value not reported) |
| Kin-Isler (2006) | 14 (m)<br>22.6 ± 2.6<br>not reported | 09:00, 13:00, 17:00 | 30s wingate test: (resistance 7.5% of body weight) [cycle ergometer] | peak power (W/kg)<br><br>mean power (W/kg) | 13:00 / 09:00<br><br>13:00 / 09:00 | 11.1 ± 1.0 / 10.6 ± 1.1 (< 0.05)<br><br>7.9 ± 0.7 / 7.7 ± 0.6 (< 0.05) |
| Kline (2007) | 12 (m) / 13 (f)<br>20.7 ± 0.6$^{SE}$<br>trained swimmers | 01:00, 04:00, 07:00, 10:00, 13:00, 16:00, 19:00, 22:00 | 200 m time trial (freestyle swimming) [50-m pool] | duration (s) | 23:00 / 05:00 | absolute values not reported |

| | | | | | | |
|---|---|---|---|---|---|---|
| Melhim (1993) | 13 (f)<br>19.5 ± 1.1<br>not reported | 03:00, 09:00, 15:00, 21:00 | 30s wingate test (resistance 0.086 kg/ kg body weight) [cycle ergometer] | peak power (W)<br><br>mean power (W) | 15:00 / 03:00<br><br>15:00 / 03:00 | 530# ± 30# / 425# ± 25# (< 0.05)<br><br>300# ± 18# / 250# ± 11# (< 0.05) |
| Petit (2013) | 13 (m)<br>17.3 ± 1.6<br>well-trained cyclists | 08:30, 10:30, 12:30, 14:30, 16:30, 18:30 | 2 x 10-s sprints [bicycle fitted in an ergometer stand] | maximal power (W) | 18:30 / 08:30 | 1022 ± 47 / 934 ± 35 (< 0.01) |
| Racinais (2004) | 15 (m) / 8 (f)<br>m: 23.1 ± 0.8, f: 21.9 ± 1.1<br>regularly active | 08:00, 13:00, 17:00 | force velocity test (repetitive 6 s sprints against increasing breaking forces, 5-min recovery) [cycle ergometer] | maximal power (W)<br><br>maximal power (W/kg) | 17:00 / 08:00<br><br>17:00 / 08:00 | 788 ± 197 / 773 ± 189 (≥ 0.05)<br><br>12.1 ± 2.3 / 11.8 ± 2.1 (≥ 0.05) |
| Reilly (1992) | 12 (m)<br>18 – 22<br>trained | 02:00, 06:00, 10:00, 14:00, 18:00, 22:00 | 30s wingate test [cycle ergometer] | peak power (W)<br><br>mean power (W) | 14:00 / 06:00<br><br>14:00 / 06:00 | 12.05 ± 3.68 / 11.15 ± 1.32 (≥ 0.05)<br><br>9.28 ± 0.97 / 8.80 ± 0.90 (≥ 0.05) |
| Souissi (2004) | 19 (m)<br>21.8 ± 0.6<br>not reported | 02:00, 06:00, 10:00, 14:00, 18:00, 22:00 | force velocity test (repetitive 6 s sprints until subjects failed to reach v ≥ 100 rev / min<br>30 s wingate test [cycle ergometer] | maximal power (W/kg)<br>peak power (W/kg)<br>mean power (W/kg) | 18:00 / 06:00<br>18:00 / 06:00<br>18:00 / 06:00 | 14.9 ± 0.4$^{SE}$ / 12.9 ± 0.4$^{SE}$ (< 0.001)<br>11.9 ± 0.2$^{SE}$ / 10.1 ± 0.3$^{SE}$ (< 0.001)<br>8.3 ± 0.2$^{SE}$ / 6.8 ± 0.2$^{SE}$ (< 0.001) |
| Souissi (2010) | 20 (m)<br>10.7 ± 0.4<br>untrained | 08:00, 14:00, 18:00 | 30 s wingate test (resistance (0.07 kg/ kg body weight) [cycle ergometer] | peak power (W/kg)<br><br>mean power (W/kg) | 14:00 / 08:00<br><br>18:00 / 08:00 | 7.0#±0.3$^{SE}$# / 6.7# ± 2.0$^{SE}$# (< 0.01)<br><br>5.7# ± 0.2$^{SE}$# / 5.4# ± 0.2$^{SE}$# (< 0.001) |
| Souissi (2019) | 15 (m)<br>20 ±1<br>PE students | 07:00, 09:00, 11:00, 13:00, 15:00, 17:00 | 5-m multiple shuttle run test [6 repetitions of 30-s maximal sprints with 35-s recovery inbetween] | total distance (m)<br><br>peak distance | 17:00 / 07:00<br><br>17:00 / 07:00 | 730.00 ± 43.92 / 698.14 ± 45.39 (< 0.05)<br><br>146.36 ± 9.39 / 129.36 ± 7.85 (< 0.05) |

| **Isometric strength tests** | | | | | | |
|---|---|---|---|---|---|---|
| Araujo (2011) | 8 (m)<br>27.0 ± 3.2<br>moderately active | 02:00, 06:00, 10:00, 14:00, 18:00, 22:00 | knee extension (d leg: MVIC at 60° flexion angle) [isokinetic dynamometer] | peak torque (Nm) | 18:00 / 06:00 | 294.9 ± 18.9$^{SE}$ / 268.7 ± 20.2$^{SE}$ (0.057) |
| Atkinson (1993) | 7 active (m)<br>23.9 ± 3.3<br>7 inactive (m)<br>24.3 ± 3.2 | 02:00, 06:00, 10:00, 14:00, 18:00, 22:00 | handgrip left/right<br>leg and back extension [portable dynamometer] | peak force (N)<br>peak force (N) | left grip:18:00# / 10:00#<br>left grip: 18:00# / 16:00#<br>not reported | 470*# / 390*# (< 0.05) (active)<br>478*# / 437*# (not reported) (inactive)<br>not reported |
| Baxter (1983) | 4 (m) / 10 (f)<br>14.7*<br>trained swimmers | 06:30, 09:00, 13:30, 17:00, 22:00 | handgrip [handgrip dynamometer] | peak force (kg) | 17:00 / 06:30 | 32.1 ± 9.6 / 30.7 ± 9.7 (> 0.05) |
| Buckner (2016) | 7 (m)<br>26.0 ± 2.0<br>trained | 2, 4, 6, 8 , 10, 12, 14 hours after wake time (05:00 – 08:00) | elbow flexion (MVIC at 60° flexion angle) [isokinetic dynamometer] | peak torque (Nm) | 4 hours after wake time /<br>12 hours after wake time<br>(no times of the day reported) | 87.1 ± 6.2 / 83.4 ± 6.8 (< 0.05) |
| Callard (2000a) | 6 (m)<br>33.4 ± 3.7<br>trained cyclists | 16:40, 20:40, 00:40, 04:40, 08:40, 12:40 | knee extension (right leg: MVIC at 65° extension angle) [isokinetic dynamometer] | peak torque (Nm) | 19:30 / 06:30# | 235.85* / 209.15* (< 0.05) |
| Callard (2000b) | 7 (m)<br>22.0 ± 0.6$^{SE}$<br>not reported | 15:00, 18:00, 21:00, 00:00, 06:00, 09:00, 12:00 | elbow flexion (left leg: MVIC at 60° flexion angle) [isokinetic dynamometer] | peak torque (Nm) | 18:00 / 09:00 | 71.5* / 68.5* (< 0.005) |
| Chtourou (2013) | 10 (m)<br>18.2 ± 1.4<br>trained judokas | 09:00, 12:30, 16:00 | handgrip (d hand) [hand dynamometer] | peak force (kg) | 16:00 / 09:00 | 54.9 ± 6.2 / 53.0 ± 6.4 **(≤ 0.05)** |
| Coldwells (1994) | 4 (m)<br>range: 21 – 30 | 02:00, 06:00, 10:00, 14:00, 18:00, 22:00 | back extension | peak force (N)<br>peak force (N) | 16:53§ / 06:00#<br>18:20§ / 02:00# | 1455.1* / 1176.2* (< 0.05)<br>1690.6* / 1411.4* (< 0.05) |

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|---|---|---|---|---|---|---|
| | physically active | | leg extension [plattform with pull-bar with dynamometer] | | | |
| Facer-Childs (2018) | ECT: 9 (m)/ 16 (f)<br>22.8 ± 4.5<br>LCT: 14 (m)/ 17 (f)<br>20.8 ± 3.0<br>not reported | 14:00, 20:00, 08:00 | handgrip (d hand) [electric hand dynamometer] | peak force (kg) | ECTs: 14:00# / 20:00#<br>LCTs: 20:00# / 08:00# | absolute values not reported (< 0.05)<br>absolute values not reported (< 0.001) |
| Freivalds (1983) | 3 (m)<br>"in their 20's"<br>not reported | Every h from 08:00 – 23:00, 02:00, and 07:00 | elbow flexion [using a strain ring and bridge ciruit] | maximum force (kg) | 16:00# / 07:00# | 37.6#* / 28.0#* (< 0.025) |
| Gauthier (1996) | 7 (m) / 6 (f)<br>m: 22.0 ± 0.6$^{SE}$<br>f: 21.8 ± 0.7$^{SE}$<br>active | 06:00, 09:00, 12:00, 15:00, 18:00, 21:00, 24:00 | elbow flexion (left arm MVIC at 90° flexion angle) [isokinetic dynamometer] | peak torque (Nm) | 17:30 / 05:30 | absolute values not reported (< 0.05) |
| Gauthier (1997) | Series 1: 4(m)/ 3(f)<br>21.0 ± 1.0<br>Series 2: 7 (m)<br>22.0 ± 1.0<br>not reported | S1: 00:00, 06:00, 09:00, 12:00, 15:00, 18:00, 21:00 / S2: 01:00, 05:00, 09:00, 13:00, 17:00, 21:00 | elbow flexion (MVIC at 90° flexion angle) [isokinetic dynamometer] | peak torque (Nm) | S1: 17:58§ / 05:58§<br>S2: 17:55§ / 05:55§ | absolute values not reported<br>absolute values not reported |
| Gauthier (2001) | 8 (not reported)<br>21.1 ± 0.4$^{SEM}$<br>trained | 01:00, 05:00, 09:00, 13:00, 17:00, 21:00 | elbow flexion (non-d arm: MVIC at 60° flexion angle) [isokinetic dynamometer] | peak torque (Nm) | 17:49§ / 05:49§ | 65.5# ± 2.5# / 57.0# ± 2.0# (< 0.05) |
| Ghattassi (2016) | 12 (not reported)<br>17.9 ± 1.3<br>not reported | 08:00, 12:00, 16:00 | handgrip (d hand) [dynamometer] | peak force (kg) | 16:00 / 08.00 | 44.5# ± 1.1$^{SE}$# / 42.7# ± 1.0$^{SE}$# (< 0.05) |

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|---|---|---|---|---|---|---|
| Giacomoni (2005) | 12 (m) / 8 (f)<br>m: 28.0 ± 4.0<br>f: 28.0 ± 4.0<br>active (3 f inactive) | 02:00, 06:00, 10:00, 14:00, 18:00, 22:00 | knee extension (MVIC at 60° flexion angle)<br>knee flexion (MVIC at 60° flexion angle) [isokinetic dynamometer] | peak torque (Nm)<br><br>peak torque (Nm) | m: 14:01§ / not reported<br>f: 12.55§ / not reported<br>m: 13:01§ / not reported<br>f: 17:17§ / not reported | 291.9* / 259.3* (≥ 0.05)<br>184.7* / 168.5* (≥ 0.05)<br>146.6* / 134.0* (≥ 0.05)<br>82.9* / 72.1* (≥ 0.05) |
| Guette (2005) | 10 (m)<br>26.4 ± 1.4$^{SE}$<br>not reported | 06:00, 10:00, 14:00, 18:00, 22:00 | knee extension (d/ non-d leg: MVIC at 90° flexion angle) [isokinetic dynamometer] | peak torque (Nm) | d leg: 18:00 / 06:00<br>non-d leg: 18:00 / 06:00 | 336.9 ± 29.4$^{SE}$ / 301.7 ± 27.9$^{SE}$ (< 0.01)<br>298.2 ± 24.6$^{SE}$ / 279.0 ± 23.3$^{SE}$ (< 0.01) |
| Hatfield (2016) | 7 (m)<br>23.6 ± 1.3<br>resistance trained | 04:00, 10:00, 16:00, 22:00 | handgrip (d/ non-d hand) [hydraulic dynamometer] | peak force (kg) | 22:00 / 04:00 | 56.0 ± 13.0 / 54.0 ± 9.0 (≥ 0.05) |
| Ilmarinen (1980) | 4 (m)<br>23.8 ± 0.7<br>well-trained | 07:00, 11:00, 15:00, 19:00, 23:00, 03:00 | handgrip (left/right) [fluid-filled dynamometer] | peak pressure (kPa) | left: 18:49 / 06:49<br>right: 18:44 / 06:44 | 73.7* / 67.2* (≥ 0.05)<br>74.2* / 68.8* (≥ 0.05) |
| Ishee (1986) | 12 (m) / 6 (f)<br>not reported<br>not reported | 09:00, 12:00, 15:00 | handgrip [handgrip dynamometer] | peak strength (kg) | 09:00 / 15:00 | 44.25 ± 16.18 / 42.69 ± 15.01 |
| Jasper (2009) | 10 (m)<br>23.8 ± 3.4<br>not reported | 09:00, 12:00, 15:00 | handgrip (left/right) [electronic hand dynamometer] | peak force (N) | left: 18:09 / 06:09<br>right: 18:12 / 06:012 | 381*# / 353*# (< 0.001)<br>431*# / 393*# (< 0.001) |
| Knaier (2019b) | 19 (m)<br>24.1 ± 2.5<br>trained | 07:00, 10:00, 13:00, 16:00, 19:00, 22:00 | leg press<br>bench press<br>trunk flexion<br>trunk extension<br>[isokinetic dynamometer] | peak force (N/kg)<br>peak force (N/kg)<br>peak force (Nm/kg)<br>peak force (Nm/kg) | 16:00 / 07:00<br>10:00 / 07:00<br>21:00 / 19:00<br>21:00 / 10:00 | 5.56 (5.16; 5.83)/ 5.31 (4.71; 5.88)^ (> 0.05) #<br>1.67 (1.43; 1.86)/ 1.58 (1.40; 1.62)^ (> 0.05) #<br>2.04 (1.87; 2.21)/ 1.96 (1.70; 2.32)^ (> 0.05) #<br>4.73 (4.14; 5.15)/ 4.37 (3.88; 5.19)^ (> 0.05) # |
| Lyddan (1971) | 10 (m)<br>18 – 20 (18.5$^{M}$) | Group A: 08:00, 11:45, 15:45, 19:45 | handgrip (preferred hand) [handgrip dynamometer] | peak force (lbs) | 22:00# / 10:00# | 139.0*# / 131.0*# (< 0.001) |

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|---|---|---|---|---|---|---|
| | not reported | Group B: 12:15, 16:15, 20:15, 00:00 | | | | |
| McGarvey (1984) | 16 (m) / 24 (f)<br>54.0* (range: 40 – 70)<br>not reported | 08:30, 12:30, 16:30 | handgrip (d/ non-d MVIC [strain-gauge grip meter]<br>hand supination (d/ non-d MVIC)<br><br>hand pronation (d/ non-d MVIC)<br><br>elbow extension and flexion (d/non-d MVIC at 90° flexion angle) [isokinetic dynamometer] | peak force (kg)<br><br>peak torque (Nm)<br><br>peak torque (Nm)<br><br>peak torque (Nm) | d grip: 16:30 / 08:30<br>non-d grip: 12:30 / 08:30<br>d hand: 16:30 / 12:30<br>non-d hand: not reported<br>d hand: 16:30 / 08:30<br>non-d hand: 12:30 / 08:30<br>not reported | 40.8 ± 12.1 / 38.3 ± 11.1 (< 0.01)<br>38.4 ± 14.4 / 36.1 ± 12.2 (< 0.05)<br>6.2 ± 2.6 / 6.0 ± 2.5 (< 0.05)<br><br>5.6 ± 2.4 / 5.3 ± 2.4 (< 0.01)<br>5.2 ± 2.3 / 5.0 ± 2.3 (< 0.01)<br>not reported |
| Pereira (2011) | 30 (m)<br>22.0 ± 1.0$^{SEM}$<br>not reported | 07:30, 13:30, 19:30 | knee extension (d leg: MVIC at 70° flexion angle) [isokinetic dynamometer] | peak force (N) | 19:30 / 07:30 | 388.0 ± 18.0$^{SE}$ / 313.0 ± 20.0$^{SE}$ (< 0.05) |
| Reilly (2007) | 8 (m)<br>19.1 ± 1.9<br>football players | 08:00, 12:00, 16:00, 20:00 | handgrip (left/right) [dynamometer] | peak strength (kg) | left grip: 20:00 / 16:00<br>right grip: 20:00 / 16:00 | 45.6 ± 9.9 / 43.1 ± 11.3 (≥ 0.05)<br>47.9 ± 11.5 / 44.7 ± 10.1 (< 0.02) |
| Sargent (2010) | 11 (m)<br>22.7 ± 2.5<br>not reported | every 2.5 hours during wake times (for 18.7 hours) | handgrip (d hand) [spring type dynamometer] | peak force (kg) | 180° / 0° (circadian phase) | absolute values not reported |
| Sedliak (2007) | 11 (m)<br>34.0 ± 8.0<br>active | 07:00, 12:00, 17:00, 20:30 | knee extension (right leg: MVIC at 120° extension angle [isokinetic dynamometer] | peak torque (Nm) | 17:00 / 07:00 | 248.0 ± 25.0 / 221.0 ± 33.0 (< 0.001) only 3 out of 11 participants were analysed |
| Sedliak (2008) | 32 (m)<br>32.0 ± 7.0<br>not reported | 07:00, 12:00, 17:00, 20:30 | knee extension (right leg: MVIC at 120° extension angle) [isokinetic dynamometer] | peak torque (Nm) | 17:00 / 07:00 | 279.9 ± 46.2 / 257.4 ± 43.2 (< 0.001) |

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|---|---|---|---|---|---|---|
| Sedliak (2011) | 17 (m)<br>27.0 ± 3.0<br>physically active | 08:00, 12:00, 16:00, 20:00 (splitted into four different sequences) | leg extension (both legs: MVIC at 107° knee angle [custom-built dynamometer] | peak force (N) | Group 1: 12:00# / 08:00#<br>Group 2: 16:00# / 08:00#<br>Group 3: 16:00# / 08:00#<br>Group 4: 20:00# / 12:00# | absolute values not reported<br>absolute values not reported<br>absolute values not reported<br>absolute values not reported |
| Souissi (2010) | 20 (m)<br>10.7 ± 0.4<br>untrained | 08:00, 14:00, 18:00 | handgrip (d hand) [handgrip dynamometer] | maximal strength (kg) | 18:00 / 08:00 | 19.4# ± 0.8$^{SE}$# / 18.6# ± 0.7$^{SE}$# (< 0.001) |
| Strutton (2003) | 5 (m) / 1 (f)<br>47.3 ± 6.1$^{SEM}$<br>not reported | 09:00, 12:00, 15:00, 18:00, 21:00, 00:00, 03:00, 06:00 | thumb adduction (d hand) [force gauge] | peak strength (kg) | 06:00# / 15:00# | 14.5# ± 5.0$^{SEM}$# / 11.5# ± 4.0$^{SEM}$# (≥ 0.05) |
| Tamm (2009) | Group 1: 6(m)/ 3(f)<br>28.0 ± 4.0<br>Group 2: 8(m)/ 1(f)<br>24.0 ± 2.0<br>not reported | 09:00, 13:00, 17:00, 21:00 | plantar-flexion (right leg) [isometric dynamometer] | peak torque (Nm) | 21:00 / 09:00 | 86.9 ± 9.0 / 79.0 ± 7.0 (< 0.001) |
| Teo (2011) | 20 (m)<br>23.8 ± 3.6<br>resistance trained | 08:00, 12:00, 16:00, 20:00 | midthigh pulls (knee angle of 130° flexion angle) [immovable bar fixed into a power rack] | peak force (N) | 16:00# / 08:00# | 2'250# ± 300# / 2'000# ± 300# (< 0.001) |
| **Isokinetic strength tests** | | | | | | |
| Araujo (2011) | 8 (m)<br>27.0 ± 3.2<br>moderately active | 02:00, 06:00, 10:00, 14:00, 18:00, 22:00 | knee extension (d leg: 1.05, 4.19 rad/s, range of 90°)<br><br><br><br>knee flexion (d leg: 1.05, 4.19 rad/s, range of 90°) | peak torque (Nm)<br><br>maximum work (J)<br><br><br>peak torque (Nm)<br><br>maximum work (W) | 1.05 rad/s: 18:00 / 06:00<br>4.19 rad/s: 18:00 / 06:00<br>1.05 rad/s: 18:00 / 06:00<br>4.19 rad/s: 18:00 / 06:00<br>1.05 rad/s: 14:00 / 06:00<br>4.19 rad/s: 18:00 / 06:00<br>1.05 rad/s: 14:00 / 06:00 | 229.8 ± 15.0$^{SE}$ / 199.2 ± 20.7$^{SE}$ (< 0.005)<br>156.7 ± 8.0$^{SE}$ / 145.1 ± 9.1$^{SE}$ (0.02)<br>240.3 ± 13.4$^{SE}$ / 208.7 ± 20.3$^{SE}$ (< 0.005)<br>177.9 ± 11.0$^{SE}$ / 161.8 ± 13.5$^{SE}$ (< 0.005)<br>123.0 ± 7.1$^{SE}$ / 109.9 ± 6.0$^{SE}$ (< 0.005)<br>120.4 ± 4.9$^{SE}$ / 110.3 ± 6.1$^{SE}$ (< 0.005)<br>152.4 ± 9.3$^{SE}$ / 129.2 ± 10.3$^{SE}$ (< 0.005) |

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|---|---|---|---|---|---|---|
| | | | [isokinetic dynamometer] | | 4.19 rad/s: 14:00 / 06:00 | 118.2 ± 6.6$^{SE}$ / 106.6 ± 8.5$^{SE}$ (0.04) |
| Bowdle (2016) | 11 (m) / 14 (f)<br>m: 20.9 ± 0.7<br>f: 20.5 ± 0.9<br>trained | 08:00, 13:00, 18:00 | knee extension (right: 60, 180, 300°/s) [isokinetic dynamometer] | peak torque (Nm) | 60°/s: 18:00# / 08:00#<br>180°/s: 18:00# / 08:00#<br>300°/s: 13:00# / 08:00# | 215.0# ± 28.0 / 192.0# ± 38.0# (0.773)<br>155.0# ± 30.0# / 145.0# ± 45.0# (0.773)<br>120.0# ± 30.0# / 105.0# ± 42.0# (0.773) |
| Deschenes (2002) | 10 (m)<br>75.6 ± 1.6<br>habitually active | 08:00, 12:00, 16:00, 20:00 | knee extension (left/right: 0.52, 1.05, 2.09, 3.14 rad/s)<br>knee flexion (left/right: 0.52, 1.05, 2.09, 3.14 rad/s)<br>[isokinetic dynamometer] | peak torque (Nm)<br>peak torque (Nm) | not reported<br>right (3.14 rad/s): 20:00 / 08:00<br>all other outcomes not reported | not reported<br>not reported |
| Deschenes (1998a) | 10 (m)<br>21.1 ± 0.6<br>active | 08:00, 12:00, 16:00, 20:00 | knee extension (left/right: 1.05, 1.57, 2.09, 3.14 rad/s)<br>knee flexion (left/right: 1.05, 1.57, 2.09, 3.14 rad/s)<br>[isokinetic dynamometer] | peak torque (Nm)<br>peak torque (Nm) | left (3.14 rad/s): 20:00 / 08:00<br>right (3.14 rad/s): 20:00 / 12:00<br>all other outcomes not reported<br>not reported | 168.9 ± 9.8$^{SE}$ / 158.3 ± 10.5$^{SE}$ **(≤ 0.05)**<br>166.3 ± 8.3$^{SE}$ / 158.0 ± 8.2$^{SE}$ **(≤ 0.05)** |
| Gauthier (2001) | 8 (not reported)<br>21.1 ± 0.4$^{SEM}$<br>trained | 01:00, 05:00, 09:00, 13:00, 17:00, 21:00 | elbow flexion (non-d arm: 1.05, 2.09, 3.14, 4.19, 5.24 rad/s, range of motion: 110°) [isokinetic dynamometer] | peak torque (Nm) | 1.05 rad/s: 17:56 / not reported<br>2.09 rad/s: 18:37 / not reported<br>3.14 rad/s: 17:22 / not reported<br>4.19 rad/s: 18:09 / not reported<br>5.24 rad/s: 17:50 / not reported | 49.0# ± 2.1$^{SEM}$ # / 45.0# ± 2.1$^{SEM}$ # (< 0.05)<br>44.1# ± 1.8$^{SEM}$#/ 40.6# ± 2.0$^{SEM}$# (< 0.05)<br>42.0# ± 1.8$^{SEM}$# / 38.1# ± 1.8$^{SEM}$# (< 0.05)<br>37.1# ± 1.8$^{SEM}$# / 35.0# ± 1.8$^{SEM}$# (< 0.05)<br>34.9# ± 1.1$^{SEM}$# / 29.8# ± 1.9$^{SEM}$# (< 0.05) |
| Giacomoni (2005) | 12 (m) / 8 (f)<br>m: 28.0 ± 4.0<br>f: 28.0 ± 4.0<br>active (3 f inactive) | 02:00, 06:00, 10:00, 14:00, 18:00, 22:00 | knee extension (d leg: 1.05, 3.14 rad/s)<br>knee flexion (d leg: 1.05, 3.14 rad/s) | peak torque (Nm)<br>peak torque (Nm) | m 1.05 rad/s: 16:58/ 06:00#<br>f 1.05 rad/s: 15:35/ 06:00#<br>m 3.14 rad/s: 17:06/ 06:00#<br>f 3.14 rad/s: 18:16/ 06:00#<br>m 1.05 rad/s: 16:25/not reported<br>f 1.05 rad/s: 13:43/not reported | 236.4* / 223.4*(≥ 0.05),<br>132.4* / 125.0* (< 0.05)<br>182.9* / 173.5* (< 0.05)<br>94.6* / 92.6* (≥ 0.05)<br>166.9* / 153.1* (≥ 0.05)<br>90.0* / 79.8* (≥ 0.05) |

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|---|---|---|---|---|---|---|
| | | | [isokinetic dynamometer] | | m 3.14 rad/s: 12:47/not reported<br>f 3.14 rad/s: 17:02/ not reported | 152.5* / 141.7* (≥ 0.05)<br>76.6* / 68.6* (≥ 0.05) |
| Hatfield (2016) | 7 (m)<br>23.6 ± 1.3<br>resistance trained | 04:00, 10:00, 16:00, 22:00 | bench press throws (30, 60 and 90% of individual 1 RM) [power rack] | force output (N) | 30% RM: 04:00 / 10:00<br>60% RM: 16:00 / 10:00<br>90% RM: 16:00 / 04:00 | 3'253 ± 1'015 / 2'857 ± 1'217 (> 0.05)<br>5'241 ± 1'725 / 4'721 ± 1'188 (> 0.05)<br>5'241 ± 1'725 / 4'500 ± 1'499(> 0.05) |
| Knaier (2019) | 19 (m)<br>24.1 ± 2.5<br>trained | 07:00, 10:00, 13:00, 16:00, 19:00, 22:00 | leg press con. 120 mm/s<br>leg press ecc. 120 mm/s<br>bench press con. 120 mm/s<br>bench press ecc. 120 mm/s<br>trunk flexion con.<br>trunk extension con. | force output (N/kg)<br>force output (N/kg)<br>force output (N/kg)<br>force output (N/kg)<br>peak torque (Nm/kg)<br>peak torque (Nm/kg) | 19:00 / 07:00<br>21:00 / 07:00<br>21:00 / 16:00<br>21:00 / 13:00<br>21:00 / 07:00<br>16:00 / 10:00 | 5.66 (4.57; 6.45)/ 4.83 (4.35; 5.07)^ (< 0.05) #<br>5.80 (4.70; 6.68)/ 5.35 (4.84; 5.80)^ (> 0.05) #<br>1.69 (1.50; 1.88)/ 1.60 (1.40; 1.73)^ (> 0.05) #<br>1.84 (1.61; 2.03)/ 1.75 (1.57; 1.86)^ (> 0.05) #<br>2.04 (1.89; 2.26)/ 1.92 (1.82; 2.19)^ (> 0.05) #<br>4.11 (3.74; 4.49)/ 4.06 (3.75; 4.20)^ (> 0.05) # |
| Sinclair (2013) | 12 (m) / 12 (f)<br>m: 22.5 ± 1.9<br>f: 21.5 ± 2.6<br>not reported | 09:00, 14:00, 18:00 | knee extension (d leg: 60°/s)<br><br>knee flexion (d leg: 60°/s) | peak torque (Nm)<br><br>peak torque (Nm) | m: 09:00 / 18:00<br>f: 14:00 / 18:00<br>m: 18:00 / 09:00<br>f: 14:00 / 18:00 | 200.1 ± 37.1 / 198.8 ± 47.3 (> 0.05)<br>137.6 ± 40.8 / 110.8 ± 16.1 (> 0.05)<br>135.6 ± 34.7 / 119.9 ± 33.0 **(≤ 0.01)**<br>90.4 ± 24.8 / 84.0 ± 15.9 **(≤ 0.01)** |
| Teo (2011) | 20 (m)<br>23.8 ± 3.6<br>resistance trained | 08:00, 12:00, 16:00, 20:00 | knee extension (1 RM squat with barbell on trapezius) | mass (kg) | 16:00# / 08:00# | 134.0# ± 27.0# / 130.0# ± 27.0# (< 0.05) |
| Wyse (1994) | 9 (m)<br>19.6 ± 0.5$^{SE}$<br>sportsmen | 08:00, 13:00, 18:00 | knee extension (1.05, 3.14 rad/s)<br><br>knee flexion (1.05, 3.14 rad/s) | peak torque (Nm)<br><br>peak torque (Nm) | 1.05 rad/s: 18:00 / 08:00<br>3.14 rad/s: 18:00 / 08:00<br><br>1.05 rad/s: 18:00 / 08:00<br>3.14 rad/s: 18:00 / 08:00 | 249.1 ± 40.0$^{SE}$ / 235.8 ± 42.6$^{SE}$ (< 0.05)<br>172.1 ± 38.7$^{SE}$ / 162.7 ± 36.6$^{SE}$ (< 0.05)<br><br>149.0 ± 32.3$^{SE}$ / 137.8 ± 31.5$^{SE}$ (< 0.01)<br>121.3 ± 27.7$^{SE}$ / 106.7 ± 30.5$^{SE}$ (< 0.01) |
| **Jump height tests** | | | | | | |
| Atkinson (1993) | 7 active (m)<br>23.9 ± 3.3 | 02:00, 06:00, 10:00, 14:00, 18:00, 22:00 | countermovement jump [pressure-activated mat] | flight time (s) | not reported | not reported |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 7 inactive (m)<br>24.3 ± 3.2 | | | | | |
| Bernard (1998) | 23 (m)<br>23.0 ± 3.0<br>not reported | 09:00, 14:00, 18:00 | multi-jump [contact platform connected to a digital timer] | flight time (s)<br><br>jump power (W/kg) | 14:00 and 18:00 / 09:00<br><br>14:00 / 09:00 | 2.76 ± 0.28 and ± 0.25 / 2.69 ± 0.24 (< 0.05)<br><br>57.7 ± 10.6 / 53.9 ± 8.8 (< 0.001) |
| Ghattassi (2016) | 12 (not reported)<br>17.9 ± 1.3<br>not reported | 08:00, 12:00, 16:00 | five jump test (joined feet position at the start and end of jumps [on grass] | total jump distance (m) | 16:00 / 08:00 | 11.2# ± 0.3$^{SE}$# / 10.6# ± 0.2$^{SE}$# (≥ 0.05) |
| Knaier (2019) | 19 (m)<br>24.1 ± 2.5<br>trained | 07:00, 10:00, 13:00, 16:00, 19:00, 21:00 | countermovement jump [force platform] | jump height (cm) | 13:00 / 07:00 | 43.1 (40.8; 44.3)/ 39.6 (36.6; 42.4)** **(≤ 0.001)** |
| Hatfield (2016) | 7 (m)<br>23.6 ± 1.3<br>resistance trained | 04:00, 10:00, 16:00, 22:00 | loaded barbell squat jump (30, 60 and 90% of individual 1 RM) [power rack] | force output (N) | 30% RM: 16:00 / 10:00<br>60% RM: 16:00 / 10:00<br>90% RM: 22:00 / 10:00 | 4'120 ± 1'892 / 3'553 ± 2'545 (> 0.05)<br>5'845 ± 2'170 / 4'324 ± 1'534 (> 0.05)<br>7'725 ± 2'843 / 6'921 ± 3'725 (> 0.05) |
| Racinais (2004) | 15 (m) / 8 (f)<br>m: 23.1 ± 0.8<br>f: 21.9 ± 1.1<br>regularly active | 08:00, 13:00, 17:00 | countermovement jump [vertical jump meter] | jump height (cm)<br><br>jump power (W) | 13:00 / 08:00 and 10:00<br><br>13:00 / 08:00 | 62.0 ± 10.0 / 60.0 ± 8.0 and ± 10.0 (≥ 0.05)<br><br>4'350.0 ± 777.0 / 4'270.0 ± 714.0 (≥ 0.05) |
| Reilly (1992) | 12 (m)<br>18 – 22<br>trained | 02:00, 06:00, 10:00, 14:00, 18:00, 22:00 | broad jump | distance (m) | 12:00 / 06:00 | 2.29 ± 0.17 / 2.16 ± 0.18 (≥ 0.05) |
| Reilly (2007) | 8 (m)<br>23.0 ± 0.7<br>football players | 08:00, 12:00, 16:00, 20:00 | countermovement jump [force platform]<br>standing broad jump | jump height (cm)<br><br>jump distance (cm) | 16:00 and 20:00 / 08:00<br><br>20:00 / 08:00 | 50.0 ± 0.9 and ± 1.0 / 45.0 ± 1.5 (< 0.05)<br><br>218.0 ± 5.8 / 206.0 ± 4.9 (< 0.05) |

| | | | | | | |
|---|---|---|---|---|---|---|
| Sedliak (2008) | 16 (m)<br>32.0 ± 7.0<br>not reported | 07:00, 12:00, 17:00, 20:30 | loaded barbell squat jump (60% of individual 1 RM) [power rack] | power output (W) | 12:00 / 07:00 | 681.3 ± 126.2 / 637.7 ± 124.2 (< 0.01) |
| Souissi (2010) | 20 (m)<br>10.7 ± 0.4<br>untrained | 08:00, 14:00, 18:00 | squat jump (~ 90° knee angle, hands crossed in front of chest) [infrared jump system]<br>five jump test (joined feet position at the start and end of jumps) | jump height (cm)<br>total distance divided by 5 (cm) | 14:00 / 08:00<br>18:00 / 08:00 | 19.5# ± 0.8[SE]# / 18.7# ± 0.5[SE]# (< 0.001)<br>153.8# ± 2.7# / 148.8# ± 2.3# (< 0.001) |
| Teo (2011) | 20 (m)<br>23.8 ± 3.6<br>resistance trained | 08:00, 12:00, 16:00, 20:00 | squat jump (~90° knee flexion angle)<br>countermovement jump [force plattform] | peak force (N)<br>peak power (W)<br>peak force (N)<br>peak power (W) | 16:00# / 08:00#<br>16:00# / 08:00#<br>16:00# / 08:00#<br>16:00# / 08:00# | 3900# ± 700# / 3250# ± 700# (< 0.001)<br>5300# ± 800# / 4750# ± 750# (< 0.001)<br>4250# ± 1000# / 3500# ± 800# (< 0.001)<br>6000# ± 900# / 5200# ± 750# (< 0.01) |
| Unver (2015) | 25 (m)<br>23.0 ± 2.4<br>trained athletes | 09:00, 14:00, 19:00 | squat jump [measurement surface] | flight time (ms)<br>jump height (cm)<br>jump power (W) | 19:00 / 09:00<br>19:00 / 09:00<br>14:00 / 09:00 | 547.3 ± 29.8[SS] / 531.7 ± 29.8[SS] (< 0.01)<br>36.9 ± 4.0[SS] / 34.6 ± 3.8[SS] (< 0.01)<br>3350 ± 463[SS] / 3217 ± 352[SS] (≥ 0.05) |

* no standard deviation reported; ^ mean (interquartile range) reported; [SE] standard error reported; [SEM] standard error of the mean reported; § estimated by cosinor analyses; [SS] sum of squares reported; # values not reported in tables data extracted from graphics.
Abbreviations: m, male; f, female; d, dominant extremity; rad/s, angular velocity expressed as radian per second; ECT, early chronotype; LCT, late chronotype; MVIC, maximal voluntary isometric contraction.

**RESULTS:**

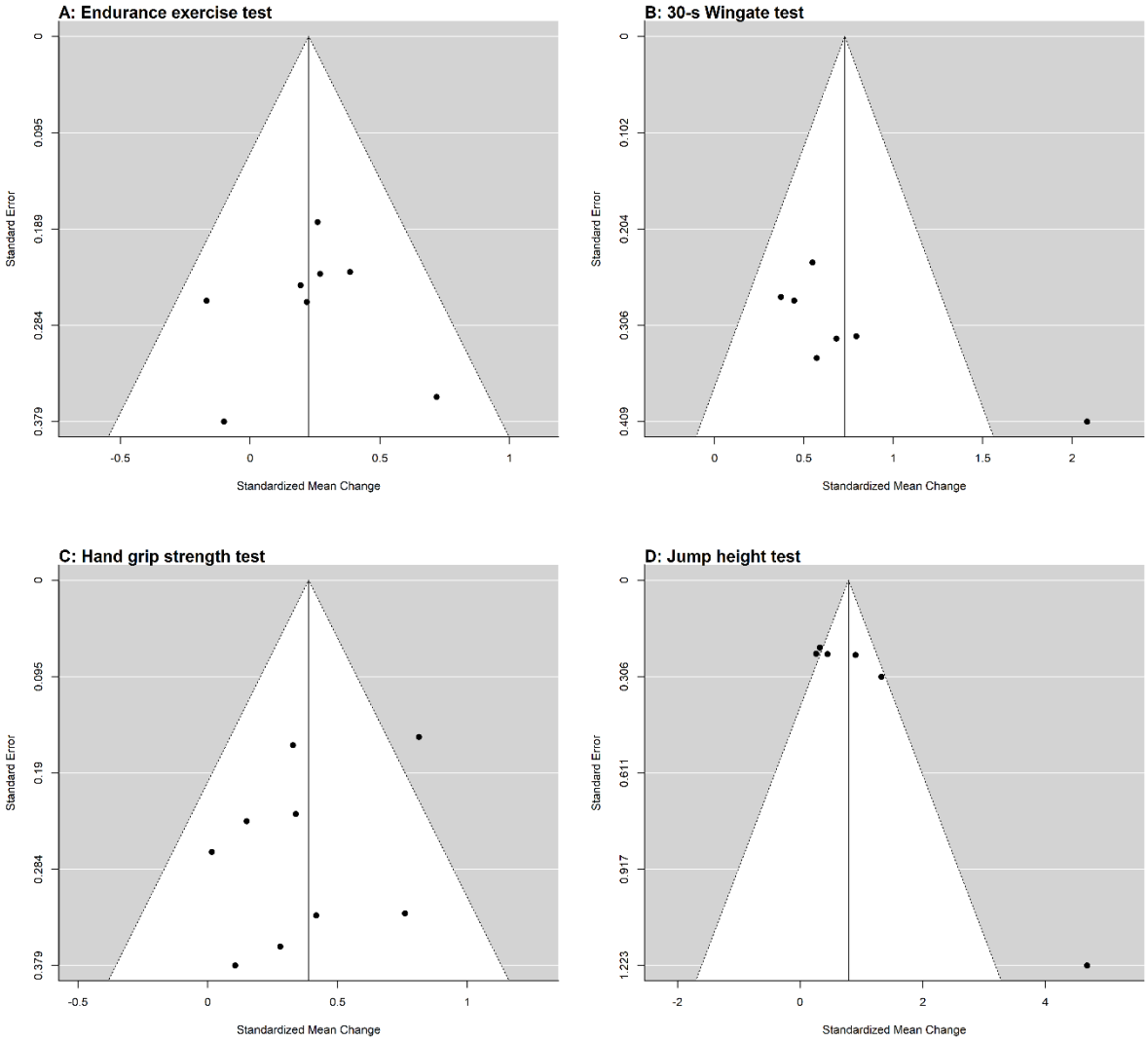


**Figure S1:** Funnel plot for standardized mean change for A: Endurance exercise tests; B: 30-s Wingate test; C: hand grip strength test; D: jump height test. Effects are calculated on an assumed correlation between within-participant measurements of r=0.8.

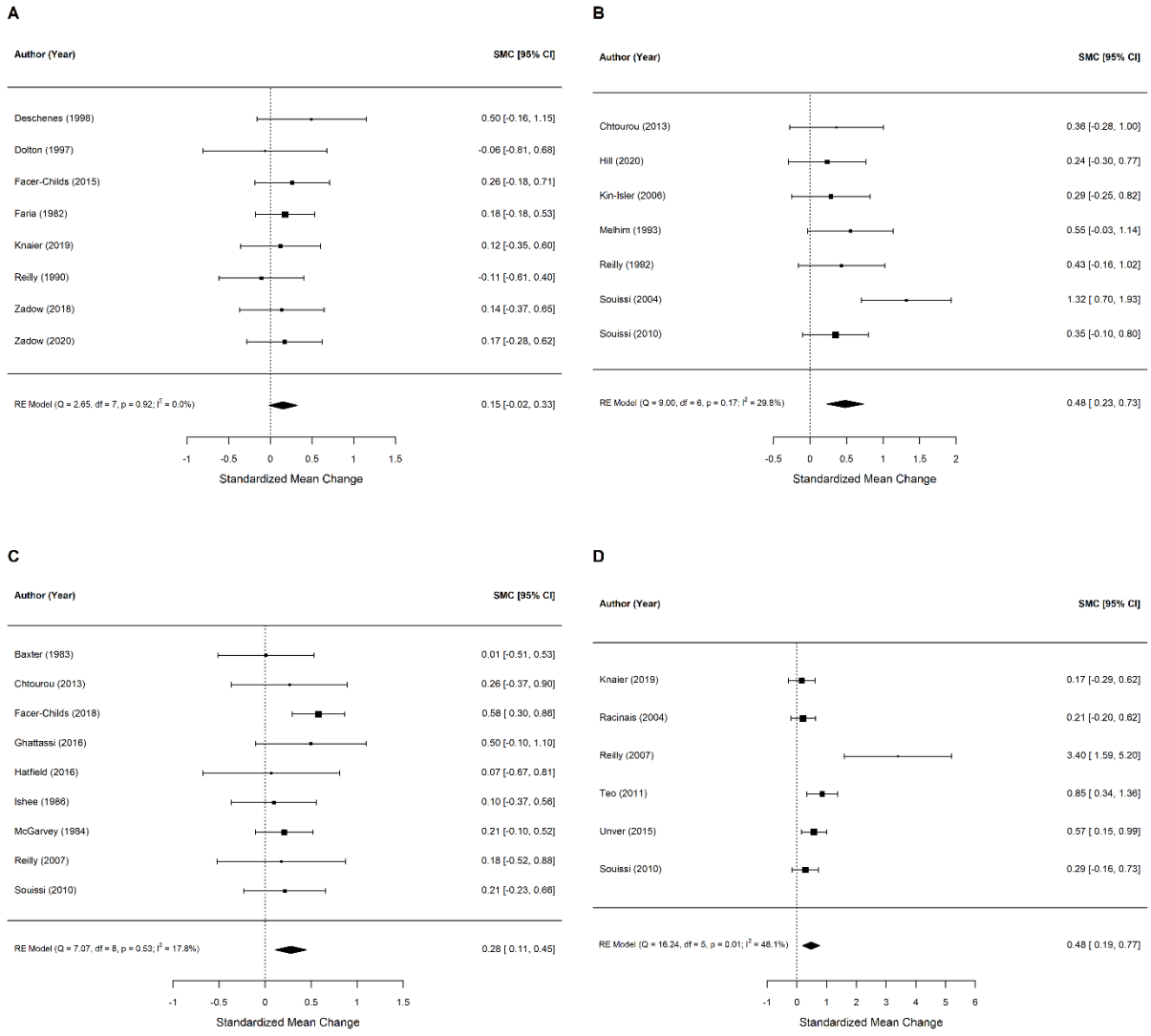


**Figure S2:** Forest plot for standardized mean change for A: Endurance exercise tests; B: 30-s Wingate test; C: hand grip strength test; D: jump height test. Effects are calculated on an assumed correlation between within-participant measurements of r=0.5