Exercise, the diurnal cycle of cortisol and cognitive impairment in older adults

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ABSTRACT

Exercise has been shown to reduce the risk of developing Mild Cognitive Impairment and Alzheimer's disease as well as to improve cognition in healthy and cognitively impaired individuals. However, the mechanisms of these benefits are not well understood. The stress hypothesis suggests that the cognitive benefits attributed to exercise may partially be mediated by changes in the cortisol secretion pattern. Chronic stress may increase the risk of AD and exacerbate the cognitive deficits and brain pathology characteristic of the condition while physical activity has been shown to attenuate most of stress consequences and risk factors for AD. Initially, research on the effects of cortisol on cognition and physical activity focused on cortisol levels at one time point but the circadian pattern of cortisol secretion is complex and it is still unclear which aspects are most closely associated with cognitive function. Thus, the aim of this review was to analyze the exercise/stress/cognition hypothesis focusing on the effects of the diurnal cycle of cortisol on cognitive function and physical activity in older adults with and without cognitive impairment.

1. Introduction

Mild Cognitive Impairment (MCI) represents a higher level of cognitive deterioration than would be expected by aging but yet not meeting the criteria for a diagnosis of dementia (Petersen, 2009) and represents a 10–18% annual risk of converting to probable Alzheimer’s Disease (AD) (Petersen, 2009; Risacher et al., 2009). There are several types of MCI, with the amnestic type (aMCI), in which memory loss is the predominant symptom, being more likely to progress to AD (Yaffe et al., 2006).

There are several risk factors for developing AD in addition to genetic factors (Corder et al., 1993). Prevalence increases with age (Querfurth and LaFerla, 2010), cardiovascular conditions (Helzner et al., 2009; Maher and Schubert, 2009; Strachan et al., 2008), oxidative stress (Querfurth and LaFerla, 2010), inflammatory markers (Parakhikova et al., 2007), and chronic stress (Rothman and Mattson, 2010). An understanding of these risk factors for the development of counter-strategies to reduce deterioration from MCI to full-blown AD remains a key priority for improving individual and public health outcomes.

Observed links between chronic stress and deterioration of cognitive function provide a focus for investigation as the biological mechanisms linking stress and cognition are increasingly understood (de Quervain et al., 2009; Dedovic et al., 2009; Lupien et al., 2007). The hypothalamic-pituitary-adrenal (HPA) axis is the major endocrine stress axis in humans. Cortisol, released in response to psychosocial and physical threat, affects metabolic, cardiovascular and central nervous systems both acutely and chronically. Basal cortisol secretion is regulated by the hypothalamic-suprachiasmatic nucleus (SCN) in response to time of day and external zeitgebers such as light (Buijs and Kalsbeek, 2001). The fine-balanced regulation of stress-induced as well as basal cortisol secretion is essential for the maintenance of homeostasis and health and dysregulation is implicated in many of the risk factors for progression to AD (McEwen, 2000; Tortosa-Martínez and Clow, 2012a; Tsikos and Chrousos, 2002). In addition to exacerbation of these physical risk factors there is evidence of direct pathways linking dysregulation of cortisol secretion and cognitive impairment, which is reviewed here alongside evidence that participation in physical activity attenuates the negative impact of chronic stress and even normalizes cortisol dysregulation, accompanied by improvements in cognition.

Disruption of biological rhythms, including dysregulation of the circadian pattern of cortisol secretion, is associated with poor mental health and is suggested to causative acting via aberrant signaling to peripheral clock genes in the brain (Menet and Rosbash, 2011). Physical and psychological stressors stimulate activity of the HPA axis which, over a prolonged period of time, can lead to changes in the...
The evidence linking diurnal cortisol secretion levels with cognition in older adults remains mainly at a cross-sectional level (Table 1).

Abnormal cortisol secretory patterns include both overall basal levels such as high morning (Beluche et al., 2010; Geerlings et al., 2015) and evening levels (Geerlings et al., 2015; high daily average (Lee et al., 2007) and Area Under the Curve (AUC) (Lee et al., 2007; Ouanes et al., 2017); and flattening of the cortisol diurnal pattern (Beluche et al., 2010; Evans et al., 2011; Kovach et al., 2011) have been associated with worse cognitive performance in healthy older adults.

Although the role of the CAR in cognitive performance remains controversial emerging evidence from carefully controlled studies suggests that larger CARs are associated with better executive function, both between and within individuals. Some studies suggest that a higher CAR indicates better overall cognition (Evans et al., 2011) or executive function (Evans et al., 2012) in healthy older adults. This line with the idea that the CAR is an adaptive response, increasing in anticipation of daily activities at awakening (Adam et al., 2006; Stalder et al., 2010). The magnitude of the CAR may decrease when impaired prospective recall precludes this anticipatory response and it seems to predict progression from healthy aging to MCI, although not to dementia (Peavy et al., 2012). Similarly, Oosterholt et al. (2015) showed that in clinical burnout an attenuated CAR was associated with poorer performance on the updating component of the ‘3-back’ task, and an increased frequency of cognitive failures although a similar relationship was not shown in healthy adults (Ennis et al., 2016). However, in a 50 day case-study of a healthy young male, days with a greater CAR predicted better same morning executive function (Law et al., 2015). This finding is again consistent with the marked state variation in the CAR and the proposal that the CAR prepares one for the day ahead (Law et al., 2013). A similar state relationship between same day larger CARs and plasticity of the motor cortex has also been demonstrated (Clow et al., 2014).

The CAR is reported to be related with some hippocampal functions such as long term memory and spatial orientation (Wolf et al., 2005) with no CAR observed in individuals with unilateral and bilateral hippocampal lesions (Buchanan et al., 2004), nor in those with severe global amnesia (Wolf et al., 2005). A larger CAR has also been associated with increased hippocampal volume in healthy young men (Fruehner et al., 2007). In an experimental manipulation, Rimmele et al. (2010) demonstrated that pharmacologic suppression of the CAR using metyrapone (a cortisol synthesis inhibitor) impaired memory for prior-day learnt text and imagery in a free recall task. In a sample of elderly participants without dementia, Geerlings et al. (2015) linked higher levels of cortisol at 45 min post-awakening with better processing speed and executive functioning, and slightly increased white matter. The results implicate a possible role of the CAR due to the timing of the cortisol assessment.

However, other studies have found an inverse correlation between the CAR and declarative and verbal memory (Almela et al., 2012; Hidalgo et al., 2016). Interestingly enough (Almela et al., 2012), found that the CAR was positively associated with working memory but only in men. This research group suggested that the CAR might be related differently to cognitive domains dependent on the hippocampus (i.e., declarative memory), than to those that are more dependent on prefrontal cortex functioning such as executive functioning (i.e., working memory). It is also possible that there is an inverted U-shaped relationship between the CAR and cognition (Moriarty et al., 2014), which might partially explain the discrepancies found in the literature.

There are only two studies examining the relationship between the diurnal cycle of cortisol and cognition in people with cognitive impairment. Wolf et al. (2002) found, with a sample of young, healthy older adults and people diagnosed with MCI, that a high average of cortisol levels indicated a worse performance in the paragraph recall, but only in those with MCI. This study did not include a CAR measurement and the first morning sample was collected at 9:00 without controlling for waking time. Also the cognitive assessment was performed within three months of the day of the salivary collection, which could bias the results in the case of people with MCI.

On the opposite side, Peavy et al. (2009) found that high average of cortisol levels were associated with a decrease rate of cognitive decline in subjects with MCI and not in healthy older adults. This is a surprising result, although it is possible that the method of measurement had an influence on the results. The researchers calculated the cortisol average based on five samples taken over the course of one day, including...
awakening and 30 min after awakening. High CAR levels could influence the total cortisol average leading to misinterpretation of the results.

In summary, although the exact relationship between cognitive function and the diurnal cycle of cortisol is not yet clarified, current evidence seems to indicate that a more dynamic cortisol secretion pattern, as opposed to a flatter profile, represents a healthier profile and a better adaption response to cognitive decline. A parallel could be established here with Heart Rate Variability (Evans et al., 2011), a dynamic autonomic measure closely related to stress, in which a higher variability is indicative of better cardiovascular health (Thayer et al., 2010) and better cognitive functioning (Thayer et al., 2009).

3. Exercise and the diurnal cycle of cortisol

Studies conducted with healthy older adults have shown a positive relationship between a more dynamic cortisol secretion pattern and physical performance but not physical activity levels (Table 2).

Physical performance was measured by different tests such as the six minute walk test and the Rockport test to assess cardiovascular performance, chair rises for lower body strength, grip strength, the timed get up and go test for dynamic balance and agility, the flamingo test for balance, and walking speed tests for assessing gait. One study (Sousa et al., 2017) used the Short Performance Battery (Guralnik et al., 1994), which combines the results of gait speed, chair stand and balance tests. Better performance in these tests are indicative of better overall health and physical functioning.

Higher morning, evening and night-time cortisol levels have been associated with lower walking speed and balance (Gardner et al., 2011; Gardner et al., 2013a; b), as well as worse cardiovascular (Lucertini et al., 2015) and overall physical performance (Sousa et al., 2017). Similarly, higher diurnal cortisol and AUC have been associated with lower walking speed and worse cardiovascular performance (Kumari et al., 2010; Lucertini et al., 2015). A lower diurnal cortisol drop and a flatter pattern, indicate lower walking speed (Gardner et al., 2011; Gardner et al., 2013a; b; Kumari et al., 2010) and higher lower body strength (Gardner et al., 2013a; b). In the three studies analyzing the relationship between the CAR and physical performance, a higher magnitude of the CAR indicated faster walking speed (Gardner et al., 2013a; b; Kumari et al., 2010; Pulopulos et al., 2016).

High levels of physical activity and physical performance have been shown to produce positive effects on brain plasticity and regional gray matter volume, especially in the hippocampus and the prefrontal areas (Erickson et al., 2013). This is of relevance not only because these areas are responsible for relevant cognitive functions, such as memory and executive function, but also because they are associated with the control of the cortisol feedback inhibition mechanism (McEwen and Morrison, 2013). Thus, it is plausible that exercise yields converging benefits in cognition and the cortisol secretion pattern (Lucertini et al., 2015). However, most evidence is based on cross-sectional studies and with healthy older adults. There are very few studies analysing the effects of exercise on the diurnal cortisol secretion pattern and cognitive function with a cognitively impaired sample, and none of them includes participants with Alzheimer’s disease. To the best of our knowledge, there are only three published studies in this regard, one cross-sectional (Dijckmans et al., 2017) and two exercise interventions (Baker and Frank, 2010; Tortosa-Martínez et al., 2015), which include a sample of older adults with aMCI.

4. The influence of exercise on cognition through changes in the diurnal cycle of cortisol

At a cross-sectional level, Dijckmans et al. (2017) showed that a greater variance in cortisol levels across the day from morning to evening was associated with better physical performance and overall cognition in a sample of healthy older adults (N = 30) and people with MCI (N = 30). No relationship was found between the CAR and cognition or physical performance. Walking speed and the Six Minute Walk Test (6MWT) were significantly correlated with both cognition and cortisol levels, indicating a link between the three variables, although
Table 1
Cross-sectional studies analyzing the relationship between the diurnal cycle of cortisol and cognition in older adults.

| Authors               | Sample                                                                 | Cortisol measurement                                                                 | Cognitive measurement                                                                                                   | Results                                                                 |
|-----------------------|------------------------------------------------------------------------|---------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------|
| Almela et al., 2012   | N = 88 (Men: 63.41 ± 4.91; Women: 63.73 ± 3.90)                        | Waking, 30', 45' and 60' after waking (two consecutive days)                           | Logical Memory and Auditory Verbal Learning Test, Spatial Span and Spatial Working Memory                               | ↑ CAR | declarative memory in men and women. ↑ CAR | working memory performance only in men. At baseline and in longitudinal analysis, ↑ morning cortisol and a flatter slope were associated with ↓ cognitive performance. |
| Beluche et al., 2010  | N = Men 111 (72.9 ± 4.4); Women 86 (72.8 ± 4.7)                        | Before cognitive testing (8h40 ± 20', 15h40 ± 40', and 21h40 ± 35'). (replicating the times in a quiet day) | Isaacs Set Test; Benton’s visual retention test; Trail Making Test B, MMSE                                               | ↑ Car | working memory performance only in men. At baseline and in longitudinal analysis, ↑ morning cortisol and a flatter slope were associated with ↓ cognitive performance. |
| Emms et al., 2016     | N = 56 M = 53.04, SD = 16.94 young (N = 17), middle-aged (N = 21), and older adults (N = 18) | Waking, 30' later, and then approximately every three hours until 9:17 p.m. on average during 10 consecutive days | Episodic memory (yes-no associative recognition task); Working memory (3-back and Reading Span); Processing speed (Letter Comparison and Pattern Comparison) | ↑ Car | working memory performance only in men. At baseline and in longitudinal analysis, ↑ morning cortisol and a flatter slope were associated with ↓ cognitive performance. |
| Evans et al., 2011    | N = 50 (73.9 ± 6.9)                                                    | Waking, 15', 30' and 45'; 3hr, 6hr,9hr, 12hr after waking (two consecutive days)       | National Adult Reading Test, the Hopkins Verbal Learning Test (HVLT), Verbal and Semantic Fluency Tests, and Trail-Making Test A and B | ↑ Car | working memory performance only in men. At baseline and in longitudinal analysis, ↑ morning cortisol and a flatter slope were associated with ↓ cognitive performance. |
| Evans et al., 2012    | N = 50 (73.9 ± 6.9)                                                    | Waking, 15', 30' and 45' (two consecutive days)                                       | Hopkins Verbal Learning Test (HVLT), and Trail-Making Test A and B                                                   | ↑ Car | working memory performance only in men. At baseline and in longitudinal analysis, ↑ morning cortisol and a flatter slope were associated with ↓ cognitive performance. |
| Geerlings et al., 2015| N = 4244 (76 ± 5)                                                      | The evening before the clinic visit, prior to going to sleep and in the morning 45' after waking | (1) memory composite score (modified version of the California Verbal Learning Test); (2) processing speed composite score, (Stroop 1 and 2, the IBST, and the Figure Comparison Test); (3) executive function composite score, (Cambridge Neuropsychological Test Automated Battery Spatial Working Memory test (short version), the Digit Backward test, and Stroop 3) | ↑ Car | executive function. ↑ morning cortisol was associated with ↑ total brain volume and cognitive performance. ↑ levels of morning cortisol were associated with slightly ↑ normal white matter volume and ↑ processing speed and executive functioning, but not with gray matter volume or with memory performance. |
| Hidalgo et al., 2016  | N = 64 (32 men, 64.4 ± 4.2; 32 women (on two consecutive days))        | Waking; 30' and 45' post-wake; 12am, 4pm, 8pm, and bedtime (two consecutive days)    | Logical Memory and Verbal Paired Associates tests Family Pictures test Letter Number Sequencing (UNS) and Digit Span (DS), Spatial Span (SS) | ↑ Car | executive function. ↑ morning cortisol was associated with ↑ total brain volume and cognitive performance. ↑ levels of morning cortisol were associated with slightly ↑ normal white matter volume and ↑ processing speed and executive functioning, but not with gray matter volume or with memory performance. |
| Kovach et al., 2011   | N = 111 (87 ± 7) older adults with dementia                            | 30' after waking, 45' after breakfast, and 45' minutes before and after dinner        | MMSE and the Cumulative Illness Rating Scale -Geriatric (CIRS-G)                                                      | ↑ Car | executive function. ↑ morning cortisol was associated with ↑ total brain volume and cognitive performance. ↑ levels of morning cortisol were associated with slightly ↑ normal white matter volume and ↑ processing speed and executive functioning, but not with gray matter volume or with memory performance. |
| Lee et al., 2007      | 642 women 325 men (61.1 ± 6.0)                                        | Before, during, and after cognitive testing as well as at visit completion           | Language, processing speed, eye-hand coordination, executive functioning, verbal memory and learning, visual memory, and visuoconstruction | ↑ Car | executive function. ↑ morning cortisol was associated with ↑ total brain volume and cognitive performance. ↑ levels of mean cortisol and AUC were associated with ↑ in all cognitive domains but visuoconstruction. |
| Ouanes et al., 2017   | N = 643 (71.5 ± 4.5)                                                  | Waking, 30' after waking, at 11 a.m. and at 8 p.m.                                   | MMSE; Grober and Buschke Double Memory Test (DMT); D040 picture naming test, the letter (phonemic) and the category (semantic) fluency tasks; Stroop Test; Consortium to Establish a Registry for Alzheimer’s Disease (CERAD); Clinical Dementia Rating (CDR) scale | ↑ AUC | CDR (indicating worse cognitive performance) |
| Peavy et al., 2009    | N = 61 healthy older adults (78.5 ± 6.4) 41 with MCI (79.2 ± 5.2). 52 were followed longitudinally (78.6 ± 5.4) | Waking; 30' post-wake; 2pm, 4pm, and bedtime                                         | Mattis Dementia Rating Scale Immediate and delayed recall from Wechsler Memory Scale—Revised | ↑ Car | CDR (indicating worse cognitive performance) |
| Wolff et al., 2002    | N = 14 young (27.0 ± 2.1); 28 healthy older adults (68.6 ± 1.2); 16 with MCI (70.9 ± 2.0) | 9 am, 11 am, 2 pm, 4 pm, 9 pm, and 11 pm                                           | GDS, MMSE, Wechsler Memory Scale Revised (paired associates and digit span) and the Guilford Memory test (paragraph recall) | ↑ Car | CDR (indicating worse cognitive performance) |

| Evans et al., 2011    | N = 50 (73.9 ± 6.9)                                                    | Waking, 15', 30' and 45' (two consecutive days)                                       | Hopkins Verbal Learning Test (HVLT), and Trail-Making Test A and B                                                   | ↑ Car | working memory performance only in men. At baseline and in longitudinal analysis, ↑ morning cortisol and a flatter slope were associated with ↓ cognitive performance. |
| Geerlings et al., 2015| N = 4244 (76 ± 5)                                                      | The evening before the clinic visit, prior to going to sleep and in the morning 45' after waking | (1) memory composite score (modified version of the California Verbal Learning Test); (2) processing speed composite score, (Stroop 1 and 2, the IBST, and the Figure Comparison Test); (3) executive function composite score, (Cambridge Neuropsychological Test Automated Battery Spatial Working Memory test (short version), the Digit Backward test, and Stroop 3) | ↑ Car | executive function. ↑ morning cortisol was associated with ↑ total brain volume and cognitive performance. ↑ levels of morning cortisol were associated with slightly ↑ normal white matter volume and ↑ processing speed and executive functioning, but not with gray matter volume or with memory performance. |
| Hidalgo et al., 2016  | N = 64 (32 men, 64.4 ± 4.2; 32 women (on two consecutive days))        | Waking; 30' and 45' post-wake; 12am, 4pm, 8pm, and bedtime (two consecutive days)    | Logical Memory and Verbal Paired Associates tests Family Pictures test Letter Number Sequencing (UNS) and Digit Span (DS), Spatial Span (SS) | ↑ Car | executive function. ↑ morning cortisol was associated with ↑ total brain volume and cognitive performance. ↑ levels of mean cortisol and AUC were associated with ↑ in all cognitive domains but visuoconstruction. |
| Kovach et al., 2011   | N = 111 (87 ± 7) older adults with dementia                            | 30' after waking, 45' after breakfast, and 45' minutes before and after dinner        | MMSE and the Cumulative Illness Rating Scale -Geriatric (CIRS-G)                                                      | ↑ Car | executive function. ↑ morning cortisol was associated with ↑ total brain volume and cognitive performance. ↑ levels of mean cortisol and AUC were associated with ↑ in all cognitive domains but visuoconstruction. |
| Lee et al., 2007      | 642 women 325 men (61.1 ± 6.0)                                        | Before, during, and after cognitive testing as well as at visit completion           | Language, processing speed, eye-hand coordination, executive functioning, verbal memory and learning, visual memory, and visuoconstruction | ↑ Car | executive function. ↑ morning cortisol was associated with ↑ total brain volume and cognitive performance. ↑ levels of mean cortisol and AUC were associated with ↑ in all cognitive domains but visuoconstruction. |
| Ouanes et al., 2017   | N = 643 (71.5 ± 4.5)                                                  | Waking, 30' after waking, at 11 a.m. and at 8 p.m.                                   | MMSE; Grober and Buschke Double Memory Test (DMT); D040 picture naming test, the letter (phonemic) and the category (semantic) fluency tasks; Stroop Test; Consortium to Establish a Registry for Alzheimer’s Disease (CERAD); Clinical Dementia Rating (CDR) scale | ↑ AUC | CDR (indicating worse cognitive performance) |
| Peavy et al., 2009    | N = 61 healthy older adults (78.5 ± 6.4) 41 with MCI (79.2 ± 5.2). 52 were followed longitudinally (78.6 ± 5.4) | Waking; 30' post-wake; 2pm, 4pm, and bedtime                                         | Mattis Dementia Rating Scale Immediate and delayed recall from Wechsler Memory Scale—Revised | ↑ Car | CDR (indicating worse cognitive performance) |
| Wolff et al., 2002    | N = 14 young (27.0 ± 2.1); 28 healthy older adults (68.6 ± 1.2); 16 with MCI (70.9 ± 2.0) | 9 am, 11 am, 2 pm, 4 pm, 9 pm, and 11 pm                                           | GDS, MMSE, Wechsler Memory Scale Revised (paired associates and digit span) and the Guilford Memory test (paragraph recall) | ↑ Car | CDR (indicating worse cognitive performance) |
Table 2
The influence of physical performance and physical activity levels on the diurnal cycle of cortisol in older adults.

| Authors                        | Sample                                                                 | Cortisol measurement | Physical activity measurement                                                                 | Results                                                                 |
|--------------------------------|------------------------------------------------------------------------|----------------------|------------------------------------------------------------------------------------------------|------------------------------------------------------------------------|
| Gardner et al., 2011           | N = 1143 (73.4 ± 4.17)                                                 | Phase 5, Waking, 30’ post-wake, 2pm, 10pm (on two consecutive days) | Get up and go test and Flamingo test                                            | ↑ Night-time cortisol levels |↓ Walking speed ↓ Balance ↓ Diurnal drop ↑ Walking speed ↓ morning cortisol, ↓ diurnal drop, ↑ CAR, ↓ night time cortisol were associated with ↑ walking speed ↓ Diurnal drop ↑ Chair rises ↑ Night time cortisol ↓ Balance No associations with grip strength |
| Gardner et al., 2013a, b       | 6 cohort studies: Boyd Orr, Caerphilly Prospective Study (CaPS); Hertfordshire Cohort Study (HCS); MRC National Survey of Health and Development (NSHD); Longitudinal Ageing Study Amsterdam (LASA); and the Whitehall II (WHII) study | Different protocols including morning levels, CAR, and rest of the day | Walking speed; Chair rises; standing balance; grip strength | ↑ morning cortisol, ↑ diurnal drop, ↑ CAR, ↑ night time cortisol, ↓ walking speed, ↓ night time cortisol, ↑ walking speed |
| Heaney et al., 2014            | N = 36, 18 men, 18 women (70.7 ± 5.66)                                 | Awakening; 30’ post-wake; 6hr, 9hr, and 12hr after waking | Physical activity scale from the West of Scotland Twenty-07 Study | No differences in cortisol measurements but ↓ levels of cortisol:DHEA ratio for those who engaged in 1hr per week of physical activity but only in the high stress group |
| Kumari et al., 2010            | N = 2802 (60.9 ± 5.9)                                                  | Waking, 30’ post-wake; 2.5hr, 8hr, and 12hr after waking, and bedtime | Walking speed over 8 feet course | ↑ basal cortisol, especially in the evening and midnight, and ↓ area-under-the-curve for total daily cortisol levels in High Fit individuals |
| Lucerini et al., 2015          | N = 22 men 68.13 ± 1.28                                                 | 30’ post-awake, 12.00, 15.00, 18.00, 21.00, 24.00 h | Rockport Walking test | ↑ basal cortisol, especially in the evening and midnight, and ↓ area-under-the-curve for total daily cortisol levels in High Fit individuals |
| Pulopulos et al., 2016         | N = 86 (64.92 ± 3.93)                                                  | Waking; 30’ post-awake; 45’ post-wake; | Walking speed: 10 min usual speed and as fast as possible | ↑ CAR ↑ Walking speed |
| Straehler et al., 2010          | N = 26 young adults (24.6 ± 2.0), 33 older adults (62.2 ± 6.7), 27 younger ballroom dancers (21.1 ± 4.4) and 31 older ballroom dancers (60.2 ± 6.8) | Waking; 30’ post-awake; 11am, 3pm, 8pm | To be included, dancers had to dance at least twice per week and compete one a month | ↑ basal salivary α-amylase ↓ amount of physical activity and aging but no effects for cortisol measurements. |
| Sousa et al., 2017             | Kingston (N = 81; 69.0 ± 2.4) Saint-Hyacinthe (N = 81; 68.3 ± 2.5) Tirana (N = 57; 69.4 ± 3.4) Manizales (N = 90; 68.9 ± 2.7) | Waking, 30’ and 60’ post-wake; 3pm, and bedtime | Short Physical Performance Battery | ↓ cortisol peak (30’ post-wake), ↑ cortisol bedtime, and ↓ ratio between these two indices indicated ↓ physical performance |
this relationship did not reach statistical significance. Baker and Frank (2010) showed that a three-month high intensity aerobic exercise program improved executive function in older adults with amnestic MCI, which was more pronounced for women than for men. Furthermore, within the exercise group, cortisol levels decreased in women while increased in men. However, this study used a one-time point cortisol measure (ranging from 8:00 to 10:00), without controlling for time of awakening. Considering the circadian pattern of cortisol, this might not be the most accurate measure.

Tortosa-Martinez et al. (2015) analyzed the effects of a three-month moderate intensity aerobic exercise program in older adults with amnestic MCI on cognition and the diurnal cycle of cortisol secretion. In this study, at baseline, better physical performance, as measured with the 6MWT and the Timed get up and go test (TUG) was associated with a higher peak of cortisol at 30 min and a subsequent drop from this peak at noon. Also better performance in the 6MWT was associated with lower cortisol values at 21:00. No correlations were found with the AUC or the CAR. These data would again indicate that more dynamic cortisol secretion pattern would be indicative of better physical performance.

After the intervention, there was a significant increase in the drop between the peak of cortisol at 30 min after awakening and the subsequent drop from this peak to noon in the exercise group. The exercise group also showed a tendency for an increased peak of cortisol at 30 min (p = 0.068) and of the magnitude of the CAR (p = 0.069). Thus, almost the same aspects of the diurnal cortisol profile found to be related to fitness at baseline were improved with aerobic exercise. An unexpected result was that total cortisol values as measured by the total mean or the AUC were not significant associations with the CAR. These data would again indicate that more dynamic cortisol secretion pattern would be indicative of better physical performance.

At the same time, the exercise group improved executive function performance, while memory remained unchanged. Other studies have implicated on cognition and the regulation of the diurnal pattern of cortisol, this might not be the most accurate measure.

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