



Informal caregiving and diurnal patterns of salivary cortisol: Results from the Whitehall II cohort study

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ABSTRACT

The objective was to investigate the relationship between various aspects of informal caregiving and diurnal patterns of salivary cortisol, with special attention to the moderating effect of sex and work status. The study population was composed of 3727 men and women from the British Whitehall II study. Salivary cortisol was measured six times during a weekday. Aspects of caregiving included the relationship of caregiver to recipient, weekly hours of caregiving, and length of caregiving. Diurnal cortisol profiles were assessed using the cortisol awakening response (CAR) and diurnal cortisol slopes. Results showed that men, but not women, providing informal care had a blunted CAR compared with non-caregivers ($P_{\text{interaction}} = 0.03$). Furthermore, we found a dose-response relationship showing that more weekly hours of informal care was associated with a more blunted CAR for men ($P_{\text{trend}} = 0.03$). Also, the blunted CAR for men was especially pronounced in short-term caregivers and those in paid work. In women, the steepest cortisol slope was seen among those in paid work who provided informal care ($P_{\text{interaction}} = 0.01$). To conclude, we found different cortisol profiles in male and female informal caregivers. Male caregivers had a blunted CAR, which has previously been associated with chronic stress and burnout. Future research should investigate whether results are generalizable beyond UK citizens with a working history in the civil service.

1. Introduction

1.1. Informal caregiving, stress, and sex

Informal caregiving, which is defined as unpaid care for a sick, disabled, or elderly family member or other closely related person (USLegal, 2017) is common in western countries. It is estimated that 34% of the population in 20 European countries provide some type of informal care for a family member, and 8% provide intensive care categorized as ≥ 11 h of care a week (Verbakel et al., 2017). Informal caregiving may be associated with positive feelings, such as sense of personal accomplishment and gratification (Yu et al., 2017). However, informal caregiving may also be perceived as stressful by the caregiver (Alfaro et al., 2013; AARP - Public Policy Institute, 2015; Wolff et al., 2016).

Informal caregiving is more common among women compared to men (Beesley, 2006; AARP - Public Policy Institute, 2015; Verbakel et al., 2017), although sex differences in informal caregiving have become less evident in recent years (Beesley, 2006). Addressing the burden of caregiving, some studies have shown that women who provide informal care take part in heavier caregiving tasks than men, and more often take the role as primary caregiver (Beesley, 2006; Navaie-Waliser et al., 2002; Neal et al., 1997; Verbakel et al., 2017), thus potentially making them more vulnerable to chronic stress (Eek and Axmon, 2014). However, little research is available to confirm or refute this hypothesis.

1.2. Cortisol as a marker of stress

A potential health consequence of chronic stress from informal caregiving is dysregulation of neural and physiological responses

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including hyper- or hypo-activation of the hypothalamic-pituitary-adrenal (HPA) axis (Dragoş and Tănăsescu, 2010). HPA activity stimulates secretion of the stress hormone cortisol by the adrenal glands (Adam et al., 2006). Cortisol levels have a natural circadian rhythm, with a high level upon awakening and a rapid increase during the first 30–45 min from awakening, called the cortisol awakening response (CAR) (Adam and Kumari, 2009;Stalder et al., 2015). Following the awakening response, cortisol levels decline until nadir around midnight (Adam and Kumari, 2009). The CAR and cortisol slope are components of the diurnal cortisol profile, which have been suggested to characterize response to acute and chronic stressors (Adam and Kumari, 2009). An increased CAR is suspected to be a marker of acute psychological stress, while a blunted CAR may be a marker of chronic stress, depression, and burnout (Leggett et al., 2015; Miller et al., 2007). Accordingly, steep cortisol slopes suggest a more rapid decline in cortisol levels throughout the day, whereas flatter cortisol slopes may indicate that the bedtime cortisol level is heightened or that the person may be in poor health status with difficulties unwinding before nighttime (Adam and Kumari, 2009).

1.3. Cortisol levels among informal caregivers

According to a recent systematic review, providing informal caregiving for a family member with dementia is associated with higher cortisol levels throughout the day, although findings and methods are not consistent across individual studies (Allen et al., 2017). Some studies found blunted CAR among caregivers (de Vugt et al., 2006; Fonareva et al., 2011) and other studies reported flattened diurnal cortisol slopes (Allen et al., 2017). A limitation in those studies is that they did not investigate specific aspects of informal caregiving, such as the relationship with the care recipient, weekly hours of caregiving as a measure of intensity, and duration of caregiving (Allen et al., 2017). It has been suggested that caregiving for a spouse may be more detrimental for health compared to caregiving for a parent (Lee et al., 2003), and providing care for a family member in the same household may be associated with more weekly hours of caregiving, which is a considerable emotional burden (AARP - Public Policy Institute, 2015). In addition, providing long-term care may be more detrimental for the caregiver's health because of the ongoing burden as opposed to short-term caregiving, (Capistrant et al., 2012a; Capistrant et al., 2012b). This raises the hypothesis that caregiving for a spouse, providing caregiving for many weekly hours, and long-term caregiving may be associated with particularly blunted CAR and flattened cortisol slopes, as markers of chronic stress (Adam and Kumari, 2009; Leggett et al., 2015; Miller et al., 2007).

1.4. The double burden of informal caregiving and paid work

Simultaneously providing informal care and being active in the labor market may constitute a double burden for the caregiver (Goode, 1960; Longacre et al., 2016). Previous analyses of data from the British Whitehall II study have shown that the CAR was greater on workdays compared to weekends, suggesting that work life is associated with acute stressors (Kunz-Ebrecht et al., 2004). However, no previous studies had the statistical power to investigate whether having paid work as an additional source of stress would increase the adverse effect of informal caregiving on diurnal cortisol levels. Thus we hypothesize that combining caregiving responsibilities with paid work may make individuals more prone to chronic stress (Goode, 1960; Longacre et al., 2016), resulting in blunted CAR and flattened cortisol slopes (Adam and Kumari, 2009; Leggett et al., 2015; Miller et al., 2007).

1.5. Study objective

To summarize, the objective of the present study was to investigate the association between informal caregiving and diurnal patterns of salivary cortisol, with special focus on the nature of the relationship

with the care recipient, weekly hours of providing caregiving, and duration of caregiving, for men and women separately. In addition, we examined whether this association was more pronounced for caregivers in paid work compared to those who are not in the labor market. Investigating this, we used data from the Whitehall II cohort study, which provides detailed data on salivary cortisol in a large population of adults with a working history in the civil service.

2. Methods

Study participants came from the Whitehall II study, which was established in 1985 and included 10,308 British civil servants from 20 London-based departments (Marmot and Brunner, 2005). We used data from phase 9 (2007–2009) due to the availability of detailed data on caregiving and cortisol. A total of 6761 people (response rate 84.5%) participated in this wave. From the 5963 people, who agreed to participate in the cortisol collection, 4128 participants had valid cortisol measures (Appendix A: Flowchart). Excluding those with missing data on caregiving information ($n = 263$) and participants with missing data information on covariates ($n = 138$), the study population encompassed 3727 participants.

2.1. Informal caregiving

People were asked if they provided regular care for any of the following in a self-administered questionnaire: a) Children, b) Grandchildren, c) Disabled or ill partner/spouse, d) Disabled or ill parent, e) Other disabled or ill relative, f) Disabled or ill friend. Participants with affirmative response to question c, d, e or f constituted the group of informal caregivers, since caregiving for children and grandchildren is not included in the definition of informal caregiving, unless they are chronically sick or disabled (USLegal, 2017).

In addition, participants were asked how many hours per week they provided care for each of these persons. In line with previous research, we classified participants into four groups depending on the hours of weekly caregiving: 1–8 h, 9–20 h, 20–100 h, and > 100 h weekly (Lee et al., 2003). Investigating duration of caregiving, long-term caregivers were categorized as those, who answered that they provided care for an aged or disabled relative in the preceding phase (2–3 years earlier) and with affirmative response to questions c, d or e, at phase 9. Short-term caregivers were categorized as those, who provided informal caregiving at phase 9, but not in the preceding phase. Category f (care for a disabled or ill friend) was not included in the analyses of duration of caregiving, since the question in the previous phase concerns caregiving for relatives only.

2.2. Cortisol

Participants were requested to provide six saliva samples in salivettes over the course of a normal weekday at waking, 30 min from awakening, 2.5 h from awakening, 8 h from awakening, 12 h from awakening, and at bedtime. Participants were instructed not to brush teeth or eat or drink anything for 15 min before sample collection. An instruction booklet was used to record information on the day of sampling including date of collection, wake time, and time each sample was taken. Participants were requested to send samples back by post. On receipt of samples, they were stored at -80°C Celsius until they were sent to laboratory in dry ice conditions for subsequent analysis. Salivettes were centrifuged at 3,000 rpm for 5 min, resulting in a clear supernatant of low viscosity. Salivary cortisol levels were measured using a commercial immunoassay with chemiluminescence detection (CLIA; IBLHamburg, Hamburg, Germany). The lower concentration limit of this assay is 0.44 nmol/L; intra- and inter assay coefficients of variance were below 8%. Any sample over 50 nmol/L was reanalyzed (Badrick et al., 2007).

2.3. Covariates

Confounders were selected based on current knowledge of factors which may influence caregiving and diurnal cortisol levels (Adam and Kumari, 2009), using Directed Acyclic Graphs (Appendix B)(Greenland et al., 1999). Analyses were adjusted for age, ethnicity, married/cohabiting, annual household income (< 20,000£, 20,000–50,000£, > = 50,000£) (Goren et al., 2014), employment status (in main effect analyses on caregiving), and wakeup time (Adam and Kumari, 2009). Based on results from a study (Burton et al., 2004) and in line with our previous studies on informal caregiving (Mortensen et al., 2016a; Mortensen et al., 2016b, we argue that lifestyle factors such as current smoking and high alcohol consumption, leisure time physical inactivity are likely to be a consequence of caregiver stress. Therefore, we have not included these factors as confounders in our analyses, as this would attenuate the effect of caregiving stress on cortisol levels mediated through these pathways. This is also the case with psychological disease such as depression, which is a likely consequence of caregiver stress (Capistrant et al., 2014; Pinquart and Sörensen, 2003).

2.4. Statistical analyses

The CAR was calculated by subtracting the cortisol measure at awakening from the cortisol measure at approximately 30 min from awakening. Conventionally, analyses were restricted to wakeup samples that were collected within 10 min of waking because of a reduced CAR in those with longer delays (Kudielka et al., 2003). Furthermore, the second measure was restricted to samples collected no later than 45 min from awakening (Kudielka et al., 2003). The CAR was further analyzed in a standard regression model:

$$Y_i = \alpha'X_i + \epsilon_i$$

where Y_i denotes the CAR, α is a vector of regression coefficients, X_i is a vector constructed from the above mentioned covariates, and ϵ_i is independent (between subjects) error terms assumed to be mean zero and with same variance. Cortisol slopes were analyzed in a multilevel linear regression model with random slopes and intercept, and hours as the time unit. In the multilevel model, measurement time was used as a level one identifier and person as a level two identifier. Interaction with time was included in the model for the caregiving exposure and included confounders:

$$\log \tilde{Y}_i = (\alpha \tilde{X}_i + \gamma \tilde{X}_{i,t_{i,j}}) + (\beta_{0,i} + \beta_{1,i}t_i) + \tilde{\epsilon}_{i,j}$$

where \tilde{X}_i is the relevant set of covariates (see above), $t_{i,j}$ is the j th measurement time of subject i , β' s are person specific random effects assumed to be mean zero, and $\tilde{\epsilon}_{i,j}$ is residual variation. The five time points from the 30 min peak until nadir was used for calculating cortisol slopes (Adam and Kumari, 2009). Because of right-skewed distributions of diurnal cortisol levels, data on cortisol slopes were log transformed. For all analyses, participants with cortisol values outside ± 3 SD of the mean were considered outliers and removed from analyses (Adam and Kumari, 2009; Stalder et al., 2015). Also, participants, who woke up before 4am or after 11am, were removed from analyses as diurnal cortisol patterns may not be accurately determined with such measurements

Table 1
Baseline characteristics of the study population.

Study population	Men (n = 2772)		Women (n = 955)	
	Caregivers (n = 286)	Non-caregivers (n = 2486)	Caregivers (n = 128)	Non-caregivers (n = 827)
Age, mean (± SD)	66 (± 6)	66 (± 6)	65 (± 6)	66 (± 6)
Married/cohabitating	84%	84%	62%	52%
In paid work	30%	32%	23%	25%
Non-Caucasian	6%	5%	10%	9%
Low annual household income (< 20,000£)	16%	13%	30%	39%

(Karlmanngla et al., 2013). Both CAR (nmol/L) and cortisol slope (log nmol/L/hour) were analyzed as the outcome in the following models, separately for men and women: We tested the difference in β -coefficients (95% CI) in the following analyses, with non-caregivers as the reference: informal caregiving, caregiving according to care recipients (either spouse or parent, relative, and friend), weekly caregiving hours categorized as 1–8 h, 9–20 h, 20–100 h, and > 100 h, and finally short- and long-term caregiving. Test for trend on weekly hours of caregiving was analyzed using the categorical variable generated. We also created four mutual exclusive categories to investigate the double burden of caregiving and work: 1. Non-caregivers, non-workers, 2. Non-caregivers, workers, 3. Caregivers, non-workers, 4. Caregivers, workers. We assessed additive interaction by including a product term in the model (von Elm et al., 2007). For difference in the CAR, a negative β represents a blunted response, while for the difference in cortisol slope, a negative β represents a steeper slope. For the CAR, Cohen’s d were calculated, with effect sizes of 0–0.20 standard deviations representing small effects, 0.20–0.50 standard deviations representing medium effects, and > 0.50 representing large effects (Cohen, 1992).

Different approaches have been suggested in analyzing the CAR (Stalder et al., 2015). Based on this, we made sensitivity analyses for CAR adjusted for the cortisol level at wakeup, and secondly we analyzed the ratio between the CAR and time difference between the wakeup measure and peak response (Adam and Kumari, 2009; Stalder et al., 2015). These other approaches to analyze the association between informal caregiving and the CAR yielded similar results as the main analyses (Appendix C). According to recommendations by International Society of Psychoneuroendocrinology, we present cortisol means and standard deviations for the cortisol response at wakeup (Stalder et al., 2015), showing that there was no difference in wakeup response for caregivers and non-caregivers (Appendix C).

3. Results

In the study population, 286 (10%) men and 128 (13%) women provided informal caregiving. In general, more men than women were married or cohabiting, and men had higher average annual household income. Among women, caregivers were more likely to be married than non-caregivers, whereas male caregivers were not more likely to be married than non-caregivers (Table 1).

3.1. Informal caregiving and cortisol

We observed a sex difference in diurnal patterns of cortisol, with male, but not female caregivers having a blunted CAR compared with non-caregivers ($P_{Interaction} = 0.03$). As seen in Fig. 1, we found that providing care was associated with a blunted CAR (β : -1.39% CI: -2.74; -0.04 (nmol/L)) (Cohen’s d = 0.14) in men. For women, we found that caregivers had a steeper CAR than non-caregivers (β : 1.33% CI: -0.86; 3.51 (nmol/L)) (Cohen’s d = 0.10), but the results were not statistically significant. For cortisol slopes, we found no difference between caregivers and non-caregivers, either for men (β : 0.001; 95% CI: -0.006; 0.008 (log nmol/L/hour)), or women (β : 0.001; 95% CI: -0.011; 0.012 (log nmol/L/hour)).

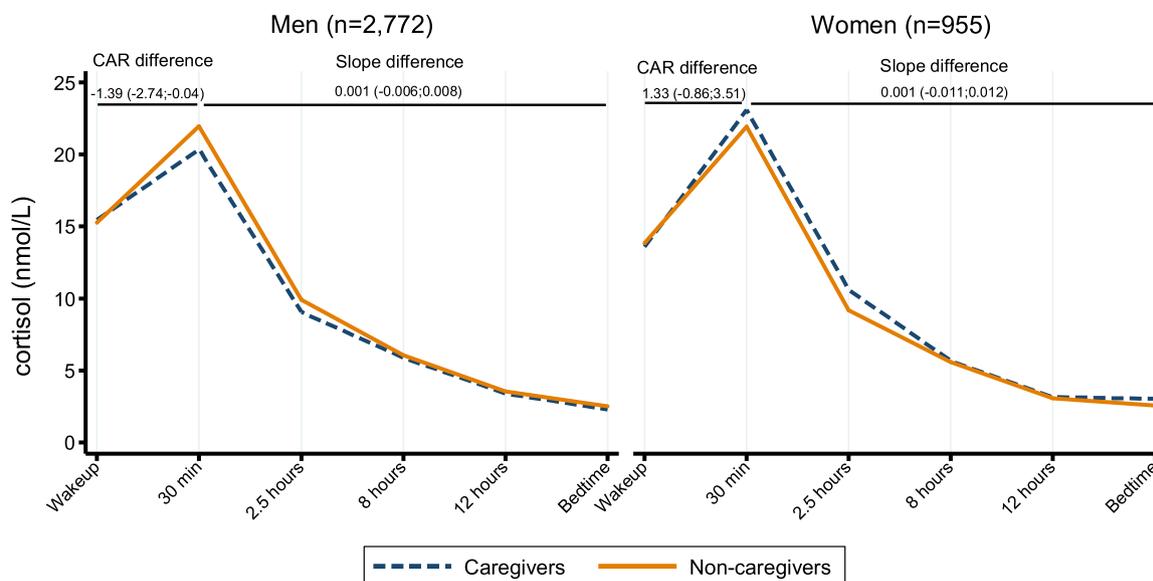


Fig. 1. Difference in cortisol awakening response (CAR) and cortisol slope for informal caregivers vs non-caregivers. The CAR estimates is presented as difference in β (95%CI) (nmol/L) and slope estimates is presented as difference in β (95%CI) (log nmol/L/hour). Multiple adjusted for age, ethnicity, marital status, employment status, income category, wake-up time. Interaction between informal caregiving and sex for the CAR ($p = 0.03$). For difference in the CAR, a negative β represents a blunted response, and for the difference in cortisol slope, a negative β represents a steeper slope.

3.2. Various aspects of informal caregiving and cortisol

As seen in Table 2, for men, we found a dose-response relationship between weekly hours of caregiving and the CAR, showing that more hours of care was associated with a more blunted CAR ($P_{\text{trend}} = 0.03$). Furthermore, among men, we found that short-term caregiving was associated with a markedly blunted CAR ($\beta: -3.27$; 95% CI: -5.35 ; -1.19 (nmol/L))(Cohen’s $d = 0.30$) and a non-significant tendency for a flattened slope ($\beta: 0.009$; 95% CI: -0.002 ; 0.020 (log nmol/L/hour)) compared with non-caregiving. The same was not found for long-term caregiving. For women, providing care for a spouse was associated with a markedly elevated CAR compared with non-caregivers ($\beta: 4.53$; 95% CI: 0.54 ; 8.51 (nmol/L))(Cohen’s $d = 0.33$).

In Appendix C1, it can be seen that among men, a mean CAR of ≤ 4 nmol/L was observed among those providing ≥ 20 h of weekly

caregiving, short-term caregivers, and caregivers in paid work. In women the lowest CAR was observed in non-caregivers and short-term caregivers with mean CAR of < 8 nmol/L.

3.3. Effect modification from work life

As seen in Table 3, male caregivers in paid work had a blunted CAR ($\beta: -3.23$; 95% CI: -5.73 ; -0.72 (nmol/L)) (Cohen’s $d = 0.26$), with a borderline significant interaction showing that this CAR was more blunted than would be suspected from the individual effects of informal caregiving and paid work ($P_{\text{Interaction}} = 0.07$). For women, there was an interaction between caregiving and paid work, with caregivers in paid work having a steeper cortisol slope than would be suspected from the effects of informal caregiving and paid work alone ($P_{\text{Interaction}} = 0.01$). Among non-caregiving women, we found that those in paid work had a

Table 2
Various aspects of informal caregiving and the association with differences in cortisol awakening response (CAR) and cortisol slopes.

	Men (n = 2772)			Women (n = 955)		
	Number (%)	Difference in CAR (nmol/L) β (95%CI)	Difference in slope (log nmol/L/hour) β (95%CI)	Number (%)	Difference in CAR (nmol/L) β (95%CI)	Difference in slope (log nmol/L/hour) β (95%CI)
Care recipient:						
Spouse	89 (3%)	-1.96 (-4.32;0.39)	0.007 (-0.006;0.019)	36 (4%)	4.53 (0.54;8.51)	-0.008 (-0.028;0.012)
Parent, relative or friend	197 (7%)	-1.32 (-2.94;0.30)	-0.002 (-0.010;0.007)	92 (10%)	0.15 (-2.47;2.78)	0.004 (-0.009;0.017)
Non-caregivers	2486 (90%)	0	0	827 (87%)	0	0
Weekly caregiving hours:						
> 100 h	33 (1%)	-2.38 (-6.15;1.40)	-0.011 (-0.030;0.009)	28 (3%)	1.40 (-3.20;6.00)	0.017 (-0.006;0.040)
20–100 h	40 (1%)	-3.17 (-6.60;0.25)	-0.015 (-0.033;0.003)	28 (3%)	1.68 (-2.75;6.10)	-0.005 (-0.027;0.017)
9–20 h	60 (2%)	-1.46 (-4.27;1.35)	0.012 (-0.003;0.027)	21 (2%)	0.52 (-4.74;5.78)	0.006 (-0.020;0.031)
1–8 h	128 (5%)	-0.37 (-2.36;1.63)	0.002 (-0.009;0.012)	40 (4%)	2.03 (-1.79;5.84)	-0.013 (-0.032;0.006)
Non-caregivers	2,485 (91%)	0	0	827 (88%)	0	0
Test for trend		$p = 0.03$	$p = 0.44$		$p = 0.29$	$p = 0.45$
Duration of caregiving:						
Long-term caregiving	142 (5%)	-0.87 (-2.74;1.00)	-0.008 (-0.018;0.003)	69 (8%)	2.04 (-0.95;5.02)	0.004 (-0.011;0.025)
Short-term caregiving	115 (4%)	-3.26 (-5.33;-1.18)	0.009 (-0.002;0.020)	39 (4%)	-0.24 (-4.07;3.59)	0.005 (-0.014;0.025)
Non-caregivers	2,421 (90%)	0	0	799 (88%)	0	0

Multiple adjusted Age, ethnicity, married/cohabiting, gainful employment, income category, and wakeup time. For difference in the CAR, a negative β represents a blunted response, and for the difference in cortisol slope, a negative β represents a steeper slope.

Table 3
Joint effects of informal caregiving and paid work on differences in cortisol awakening response (CAR) and cortisol slopes.

	Men (n = 2772)			Women (n = 955)		
	Number (%)	Difference in CAR (nmol/L) β (95%CI)	Difference in slope (log nmol/L/hour) β (95%CI)	Number (%)	Difference in CAR (nmol/L) β (95%CI)	Difference in slope (log nmol/L/hour) β (95%CI)
Caregivers, in paid work	86 (3%)	-3.23 (-5.73;-0.72)	0.004 (-0.003;0.009)	30 (3%)	-0.27 (-4.79;4.26)	-0.014 (-0.036;0.009)
Caregivers, not in paid work	200 (7%)	-0.71 (-2.33;0.91)	0.000 (-0.008;0.009)	98 (10%)	1.41 (-1.16;3.98)	0.009 (-0.003;0.022)
Non-caregivers, in paid work	805 (29%)	0.23 (-0.86;1.31)	0.002 (-0.008;0.018)	206 (22%)	-1.79 (-3.97;0.40)	0.014 (0.004;0.025)
Non-caregivers, not in paid work	1,681 (61%)	0	0	621 (65%)	0	0

Multiple adjusted Age, ethnicity, married/cohabiting, gainful employment, income category, and wakeup time. CAR interaction: men $p = 0.07$, women $p = 0.97$. Slope interaction: men $p = 0.84$, women $p = 0.01$. For difference in the CAR, a negative β represents a blunted response. For the difference in cortisol slope, a negative β represents a steeper slope.

flattened slope relative to those, who were not in paid work (β : 0.014; 95% CI: 0.004;0.025 (log nmol/L/hour)). Unadjusted and multiple adjusted analyses yielded similar results (Appendix C2-C3).

4. Discussion

We found that male caregivers had a blunted CAR compared to non-caregivers, which was especially pronounced among those providing many weekly hours of care, among short-term caregivers and caregivers in paid work. For women, spousal caregivers had a greater CAR than non-caregivers, while caregivers in paid work had a steeper cortisol slope than would be expected from the individual effects of caregiving and paid work.

In a recent systematic review, being caregiver for a family member with dementia was associated with higher cortisol levels throughout the day (Allen et al., 2017), and studies included in the review, found a blunted CAR in caregivers compared with non-caregivers (de Vugt et al., 2006; Fonareva et al., 2011). This association was driven by higher cortisol levels at wakeup for caregivers compared with non-caregivers. In line with this, individuals with low wakeup-levels of cortisol tend to have a steep CAR, whereas individuals with high wakeup levels have a blunted CAR (Stalder et al., 2015). We found that male caregivers had a blunted CAR compared with non-caregivers in a dose-response relation, showing that more weekly hours of caregiving were associated with a more blunted CAR. However, in contrast to studies included in the review (de Vugt et al., 2006; Fonareva et al., 2011), we found no difference in cortisol levels at wakeup between caregivers and non-caregivers.

For women, we found that caregivers tended to have a steeper CAR compared with non-caregivers, which was statistically significant for spousal caregivers. We hypothesized a blunted CAR as a result of chronic stress or burnout, and we hypothesized that this would be more pronounced for spousal caregivers (Lee et al., 2003), because of high intensity caregiving from living in the same household (AARP - Public Policy Institute, 2015). However, the elevated CAR observed in spousal caregivers may be a consequence of acute stress reactivity in the morning. This response may not necessarily be unhealthy, since results suggest that women providing spousal caregiving do not have flatter cortisol slopes than non-caregivers, indicating that they do not have more difficulties unwinding in the evening.

The blunted CAR observed among male caregivers compared with female caregivers is unexpected. It was hypothesized that female caregivers would have higher risk of chronic stress, due to previously proposed heavier caregiving duties, and therefore a blunted CAR compared to their male counterparts (Beesley, 2006; Navaie-Waliser et al., 2002; Neal et al., 1997; Verbakel et al., 2017). However, from a historical perspective, women have had more household chores than men have, and may therefore be more resilient to potential stress from assisting with personal care and household chores for an ill or disabled relative. Thus, one explanation of our findings could be that a woman

providing care for her disabled husband would have more resources to deal with this challenge, than a man providing care for his disabled wife. This hypothesis should be addressed in future studies.

We stratified analyses by work status and found that male caregivers in paid work had a blunted CAR compared to male non-caregivers who were not in paid work. For women, we found an interaction showing that caregivers in paid work had a steeper cortisol slope than would be expected from the effects of caregiving and work alone. A higher peak did not explain this result, as we did not find a higher CAR for working women also providing care. Steeper slopes have previously been associated with better health status, as it may indicate that these individuals find it easier to unwind before bedtime (Adam and Kumari, 2009). Thus, our result may point to a 'healthy caregiver effect', where more privileged women, who provide care, stay in the labor market due to good working conditions, in contrast to less privileged women, who quit the labor market because of caregiving responsibilities. This explanation is partly supported by previous findings, which shows that less privileged individuals have flatter cortisol slopes (Karlman et al., 2013).

In contrast to our hypothesis, we found that short-term caregiving and not long-term caregiving, was associated with a blunted CAR in men. A possible explanation may be that long-term caregivers have learned to cope with the role as caregiver, whereas short-term caregivers may struggle with adapting to the new role and the associated life changes. In line with this, a study among informal caregivers who were in paid work have shown that in severe care situations, caregivers adapt their work situation by taking time off work or having flexible work arrangements (Oldenkamp et al., 2017); which may explain why the caregiving burden among those in paid work may be diminished in long-term caregivers.

It has been proposed that cortisol concentrations measured in saliva in healthy adults increase by 50% to 160% in the first 30 min post-awakening, corresponding to an average increase of 9 nmol/l (range 4–15 nmol/L) (Clow et al., 2004). Based on this, a CAR of less than 4 nmol/L with medium effect sizes (Cohen, 1992), which was observed among male caregivers providing ≥ 20 h of weekly care, male short-term caregivers, and male caregivers in paid work, seems to be an unhealthy awakening response.

4.1. Methodological considerations

The study population encompassed British adults with a working history in the civil service, of whom most had retired. This should be taken into consideration when generalizing the results. A limitation of this study is that cortisol was measured on a single weekday, and may therefore not necessarily be representative of participants' diurnal cortisol levels in general. In future studies, having cortisol measures for several weekdays would strengthen the evidence (Karlman et al., 2013). Another limitation is that we had no information on whether participants provided care for disabled or chronically ill children. Thus,

there could potentially be informal caregivers in the non-caregiving group, who were not identified by the questionnaire. This misclassification could attenuate the true effect of informal caregiving on diurnal cortisol levels. Furthermore, we had no information on the type of caregiving provided or the severity of the disease of the care recipient. There may be large differences in the caregiving burden, based on whether providing assistance with e.g. personal care or grocery shopping (AARP - Public Policy Institute, 2015). In addition, caregiving for a spouse or parent with dementia may constitute a greater caregiving burden than care for a disabled relative with no cognitive deficits (Allen et al., 2017).

A high number of eligible participants did not return cortisol samples, probably due to the cumbersome task of collecting six saliva samples at particular time intervals. This non-compliance was prevalent in older participants and in participants with higher household income, but did not depend on sex. It is possible that non-compliance is most common among those who are mostly stressed by the burden of informal caregiving. If this was the case, then our results would have presented a more healthy stress response in informal caregivers, than would be seen in the total population of eligible participants; thus biasing results towards the null.

Almost three quarters of the study population were men, which could be considered as a strength, since many studies on informal caregiving are primarily based on women. However, there may have been insufficient power to observe an association in women due to smaller numbers. On the other hand, we found that sex modified the association statistically significantly, showing that male caregivers had a blunted CAR compared with female caregivers. Thus, although only a modest difference in the CAR was observed among men and women, these sex differences are interesting since most previous research on informal caregiving have highlighted that women may be more prone to stress from caregiving, due to a greater caregiving burden in women, compared with men (Navaie-Waliser et al., 2002; Verbakel et al., 2017).

4.2. Conclusion

To our knowledge, this is the first study investigating various aspects of informal caregiving in relation to diurnal cortisol levels. For male caregivers, we found a blunted CAR, which in other studies has been associated with chronic stress and burnout. This observed association was especially pronounced for those providing many weekly hours of care, short-term caregivers, and caregivers in paid work. Among women, the tendency was the opposite, showing an elevated CAR in spousal caregivers compared with non-caregivers. Furthermore, female caregivers in paid work had a steeper cortisol slope than would be expected from the individual effects of caregiving and paid work, indicating a healthy caregiver effect among these women.

Our findings show that men and women providing informal caregiving may have different cortisol profiles, and future studies should investigate whether women providing informal caregiving to a close relative are more resilient to caregiver stress than their male counterparts. Further research is also needed to investigate whether results are generalizable beyond UK citizens with a working history in the civil service; preferably with saliva cortisol measures from several consecutive days or with cortisol from hair, which has been proposed to be a better approach in measuring response to chronic stress.

Conflicts of interest

The authors have no competing interests to declare.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:<https://doi.org/10.1016/j.psyneuen.2018.09.030>.

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