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Stress-buffering effects of volunteering on salivary cortisol: Results from a daily diary study

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A R T I C L E I N F O

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A B S T R A C T

Based on the theoretical foundations of the caregiving system model, which holds that prosocial behavior can be conceptualized in relation to a neurobiological stress-buffering mechanism, we addressed the question of whether daily volunteering yields buffering effects in terms of suppressing a neuroendocrine response (i.e., salivary cortisol) to daily stressors. We used daily diary data from the second wave of the National Study of Daily Experiences (NSDE II), which is part of the Midlife in the United States study (MIDUS II), a nationally representative survey of middle-aged and older adults. Analyzing a sample of volunteers ($N = 340$), we tested the buffering role of daily volunteer work for the same day stressors-salivary cortisol response relationship (person-day observations, $N = 1{,}042$). Findings from multilevel models indicated that the relationship between daily stressors and cortisol output was attenuated on days when volunteering was performed compared to days volunteering was not performed. Our findings are suggestive of a unique, but unobserved, neurobiological mechanism underlying the link between volunteering and better health. Volunteer programs designed to help others in need may be considered as an intervention strategy for individuals living under stressful conditions.

1. Introduction

There is now an extensive literature on the salubrious health effects of volunteering among older adults (Anderson et al., 2014). Various mechanisms have been proposed and tested to explain the link between volunteering and health. The mechanisms include those that are explained by the social features of volunteering, such as the context of a formal organizational structure within which the activity is conducted and the social role it provides (Greenfield and Marks, 2004; Mutchler et al., 2003), as well as the social support, social control, and interpersonal relationships generated by this activity (Fried et al., 2004; Han et al., 2017). Other research focuses on the psychological benefits associated with volunteering, such as increases in mastery (Thoits and Hewitt, 2001) and self-efficacy (Müller et al., 2014). Recently, the focus on the positive social and psychological aspects of volunteering has been extended to factors that are more neurobiological in nature, and researchers are beginning to uncover empirical evidence of the association between volunteering and markers across distinct human biological and physiological systems (Burr et al., 2016; Kim and Ferraro, 2014; Nelson-Coffey et al., 2017). Prosocial behavior, such as formal volunteering, can be conceptualized in relation to a neurobiological "caregiving system" in the human brain that is health-promoting via a stress-buffering mechanism (Brown and Brown, 2017). This approach provides theoretical grounding for the "under the skin" association between volunteering and health. Despite these advances, empirical evidence for the stress-regulatory function of volunteering is rare and requires further evaluation.

The aim of this study is to investigate the association between volunteering and health from a neurobiological perspective framed within the caregiving system model. Specifically, we employ data from a daily diary study to test whether volunteer activity suppresses a specific neuroendocrine response (i.e., cortisol secretion) to stress that individuals experience on a daily basis. This daily diary design also offers an opportunity to reduce shortcomings associated with social selection processes found in earlier studies of volunteering and health (i.e., healthy volunteer effect; Li and Ferraro, 2005) by taking a within-person analytic modeling approach, where subjects are treated as their own controls. To our knowledge, no other study to-date has examined the stress-buffering effects of volunteering for cortisol levels using a daily dairy study design.

1.1. *The caregiving system model*

The caregiver system model (CSM; Brown and Brown, 2017; Brown and Cialdini, 2015) integrates accumulated insights from multidisciplinary research on prosocial behavior that provides a framework

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for the neurobiology of prosocial behavior, as well as a theoretical basis for understanding the health benefits associated with helping behavior. Formal volunteering, commonly defined as unpaid work performed under the auspices of a formal organization with the intent of benefitting others, is considered a relevant marker of prosocial behavior within this framework (Brown and Brown, 2017; Morrow-Howell, 2010). However, according to the CSM, it is volunteer activity directed towards caring for others in need, and not work directed towards other more impersonal purposes, that is relevant to the neural and hormonal caregiving system developed over the long history of human evolution (Brown and Brown, 2017).

The CSM posits that social bonds and interdependence between individuals enable persons to provide help to those in need without being exploited (Brown and Brown, 2017). The central argument of the model is that when a person perceives others are in need of help, there is an interaction between social and neurobiological factors (e.g., social bonding, interdependence, hormonal correlates) and available resources (e.g., ability to help, history of providing and receiving care). In this context, the medial preoptic area (MPOA) of the hypothalamus activates the caregiving system in the brain (Brown and Cialdini, 2015). The caregiving system in turn promotes helping behavior by increasing the other-focused motivation to actively provide care (via empathy and compassion), as well as by inhibiting motivations that compete with providing care (e.g., self-serving or reward-seeking behavior). That is, the motivational conflict of moving beyond self-interest to provide help for others is reconciled through a stress regulation process (Brown and Brown, 2017; Brown and Cialdini, 2015). The neuroendocrine modulation involving specific hormones, such as oxytocin (OT) and arginine vasopressin, is considered to be instrumental to the model, as these hormones play key roles in social bonding, being primed to meet the needs of others, and stress regulation in the processes of the activation and maintenance of the caregiving system (Brown and Cialdini, 2015; MacDonald and MacDonald, 2010).

Apart from providing an explanation for the neurobiological mechanisms that guide helping behavior, the CSM also provides a framework that explains the widely documented health benefits for the helper that is often restricted to helping behaviors based on an other-focused motives (e.g., volunteering) and not those based on self-serving motivations, such as obligation (e.g., caregiving; Anderson et al., 2014; Brown and Brown, 2017; Burr et al., 2017). The health benefits associated with the other-focused helping behavior can be explained by the stress-buffering mechanism underlying the caregiving system and its hormonal correlates, which are known to have downstream health benefits (Brown and Cialdini, 2015). In particular, increased levels of OT associated with helping others attenuate the physiological and psychological responses to various forms of stress that individuals experience, through neuroendocrine mechanisms involving the hypothalamus-pituitary-adrenal (HPA) axis functioning (Heinrichs et al., 2009). The OT hormone has been a major focus in the stress-buffering literature, and its role in dampening the HPA response to stress has been widely documented, where a large body of research using human subjects has indicated the stress-buffering effects of OT on stress hormones, especially salivary cortisol (for a review, see Hostinar et al., 2014). To be clear, we do not interpret the CSM to indicate that prosocial behaviors like volunteering under the auspices of formal organizations are directly related to the release of healthy hormones. Rather, the CSM provides a foundation for expecting such pro-social helping behaviors to help regulate the relationship between stress and the release of these hormones (for a detailed description of the neurobiological basis for the stress-buffering mechanism underlying the CSM, refer to Brown and Brown, 2017).

1.2. Daily stress and stress reactivity

The role of stress for health and well-being is well-established in the literature (Acabchuk et al., 2017; Thoits, 2010) and there is increasing evidence that accumulation of minor stressors experienced on a daily basis, often described as daily hassles (e.g., arguments with others, work deadlines), is a critical determinant of health (Almeida et al., 2011). Further, it is not exposure to these stressors that is important for health outcomes per se, but rather it is the individual variation in reactivity to stressors that accounts for variability in health (Almeida et al., 2011). One of the key physiological markers of stress reactivity is the release of cortisol from the adrenal cortex. Although cortisol plays an essential role in stress regulation, elevated and chronic exposure to this stress hormone is detrimental for physical and mental health (Piazza et al., 2010). In this study, we examine overall secretion of diurnal cortisol (i.e., from wake time to sleep time) assessed daily, an indicator of cortisol output known to be associated with daily stressors (Stawski et al., 2013).

1.3. The stress-buffering effects of volunteering

Despite the extensive literature on volunteering and health, studies that examine the stress-buffering effects of volunteering are limited. Two studies based on U.S. samples show mixed findings; volunteering did not buffer the detrimental effects of role-loss on affective well-being in later life (Greenfield and Marks, 2004), but the activity was shown to buffer the adverse effects of widowhood on depressive symptoms (Li, 2007). Additional evidence of the stress-buffering effects of volunteering comes from a study framed by the CSM, where Poulin (2014) shows that a greater number of hours devoted to volunteering was protective against stressful life events (e.g., serious illness, natural disaster). Further evidence on the stress-buffering hypothesis comes from studies on other forms of helping behavior. A recent daily diary study by Raposa et al. (2016) demonstrates that prosocial behaviors (e.g., holding an open door, asking someone if they need help) directed toward strangers and acquaintances attenuates the negative effects of daily stressors on psychological health outcomes. Other studies regarding prosocial behaviors indicate that instrumental help provided to family members and friends (Brown et al., 2008), social support given to others in a religious setting (Krause, 2006), and charitable behaviors, such as donating blood or giving money to charity (Poulin and Holman, 2013) buffer the adverse effects of stress. Importantly, Poulin and Holman (2013) provide evidence that different genotypes associated with the OT receptor gene account for the stress-buffering effect, thereby providing some support for the CSM.

1.4. Study question and hypothesis

Guided by the CSM and recent findings from the empirical literature, we address the question of whether volunteering provides a buffer for the neuroendocrine reactivity (as measured by diurnal cortisol secretion) to daily stressors. To reiterate, the hypothesized relationship between volunteering and stress-reactivity is related to a stress-buffering mechanism. The CSM does not provide theoretical grounding to expect a direct relationship between volunteering and cortisol output. We assume that volunteer work activates the caregiving system, promoting the secretion of OT (unobserved in this study due to data limitations). Thus, we hypothesize that the relationship between daily stressors and cortisol response among volunteers will be attenuated on days when individuals volunteer as compared to days when they do not volunteer.

2. Design and methods

2.1. Data & study sample

The data were taken from the second wave of the *National Study of Daily Experiences* (NSDE II; Almeida et al., 2009), which is a random subsample of the *National Survey of Midlife Development in the United States* (MIDUS II), representative of Americans ages 35 to 84 (Brim et al., 2004). A total of 2022 respondents in the NSDE were contacted for daily diary telephone interviews on their experiences for eight consecutive evenings. On days 2 through 5 of the 8-day observation period, respondents provided four saliva samples throughout the day: (a) upon waking, (b) 30 min after getting out of bed, (c) before lunch, and (d) at bedtime. The daily diary data for this study came from the 4 days where saliva samples were collected (for detailed information of the saliva collection, cortisol assay, and NSDE in general, refer to Almeida et al., 2009).

The objective of this study was to examine within-person relationships between daily stressors, volunteer work, and stress reactivity; therefore, the study sample was constrained to those who were self-identified as volunteers. Because the stress-buffering mechanism theorized in the CSM is specific to helping behavior that is interpersonal in nature, we defined the study sample of volunteers using information from the main MIDUS survey; this information was unavailable from the NSDE (see below). In the core MIDUS survey, respondents were asked how many hours per month, on average, they spent doing formal volunteer work for each of the following: (a) hospital, nursing home, or other healthcare-oriented volunteer work; (b) school or other youth-related volunteer work; (c) volunteer work for political organizations or causes; and (d) volunteer work for any other organization, cause, or charity. Based on responses to these items, we first selected individuals identified as monthly volunteers for either (a) or (b), given the relevance of these volunteer activities for helping others in need, such as persons who are ill or young people ($N = 566$). Therefore, the specific type of volunteer work actually conducted each day is assumed based on self-reports of the type of monthly volunteer activity in which they engaged. The data file does not contain information on type of daily volunteer activity. The implications of this sampling strategy and related limitations are addressed later in the discussion section.

Respondents who self-identified as volunteers but who did not meet other sample criteria were excluded. These included those who did not provide saliva samples ($n = 72$) or time stamps for the samples ($n = 2$), as well as individuals with irregular daily schedules (i.e., nightshift workers; $n = 4$). Further, respondents whose cortisol levels were outside of the normal range (i.e., > 60 nmol/l), or for whom the before lunch sample was ≥10 nmol/l more than the 30-min post-waking sample were excluded. As well, respondents were excluded if they reported they were awake for less than 12 h or more than 20 h during the day, or reported less than 15 min, or more than 60 min between the first and second saliva samples (Stawski et al., 2013). These exclusions yielded a sample with 1,072 usable days of data from 351 respondents. Finally, respondents with missing information on other study variables were excluded ($n = 11$). The final analytic sample included 340 respondents who provided data for 1,042 person-days.

2.2. Measures

2.2.1. Total cortisol output

The total cortisol output during each of the four saliva collection days was calculated using the area under the curve (AUC), widely used in endocrinological research. Specifically, we used area under the curve with respect to the ground (AUC_G) trapezoid formula recommend by Pruessner et al. (2003) to assess the overall secretion of diurnal cortisol (i.e., from wake time to bedtime):

$$AUC_G = \frac{(\text{out of bed cortisol} + \text{wake up cortisol})\cdot t_1}{2} + \frac{(\text{before lunch cortisol} + \text{out of bed cortisol})\cdot t_2}{2} + \frac{(\text{bed time cortisol} + \text{before lunch cortisol})\cdot t_3}{2}$$

with t_1, t_2, and t_3 denoting the temporal distance between each subsequent measurement (i.e., saliva collection). The computed AUC_G measurements were then transformed by the natural log to adjust for skewness (range = 1.92–6.10).

2.2.2. Daily stressors

The Daily Inventory of Stressful Events index (DISE; Almeida et al., 2002) was used to assess daily stressors. Each evening, respondents were asked a series of stem questions regarding whether they had experienced each of the following seven stressors in the past 24 h: arguments, potential arguments, work stressors, home stressors, network stressors (i.e., stressors that happened to other people in respondent's network), discrimination stressors, and other stressors. Dichotomous responses (1 = *experienced stressor*; 0 = *did not experience stressor*) to the seven items were then summed, with higher scores indicating more daily stressors (i.e., total number of daily stressors). Respondents reported more than three stressors in less than 1% of 1,440 the study days; therefore, the measure was top-coded at three or more stressors (range = 0–3). To ensure that our results were not sensitive to the coding strategy, we evaluated an alternative measure of daily stress, where a dichotomous measure for *any stresso*r experienced was coded as 1 when respondents gave an affirmative response to any of the seven items. Results from this sensitivity analysis were consistent with results using the continuous measure of daily stress (see Supplementary Table 1).

2.2.3. Daily volunteering

Daily involvement in formal volunteering was assessed with the question, "Since (this time we spoke) yesterday, did you spend any time doing formal volunteer work at a church, hospital, senior center, or any other organization?" If a respondent worked at places such as a church or nursing home, they were considered as volunteering only if the respondent was not financially compensated. Volunteering on a given day was coded dichotomously (1 = *yes*; 0 = *no*).

2.2.4. Daily covariates

We considered several measures known to influence daily salivary cortisol output. Daily wake time was considered in relation to respondents' average time of awakening during the study period, with higher values indicating later than usual wake time (Kudielka and Kirschbaum, 2003). Taking medications (i.e., allergy medications, steroid inhaler, steroid medications, cortisone, birth control pills, other hormones, antidepressants, and anxiety medications) known to interact with HPA activity was coded as 1 = *at least one medication*, 0 = *no medication* (Granger et al., 2009). Day of the week was coded as 1 = *Monday through Friday*, 0 = *Saturday and Sunday* (Kunz-Ebrecht et al., 2004).

2.2.5. Background characteristics

Several sociodemographic and health measures were also included in the models. Sociodemographic covariates included age (in years), gender (1 = *woman*; 0 = *man*), race (1 = *White*; 0 = *non-White*), working for pay (1 = *yes*; 0 = *no*), and education level (1 = *some high school/high school graduate* (reference category); 2 = *some college/college graduate*; 3 = *some graduate school or above*). Measures for general health included body mass index (in kg/m^2) and self-rated health, ranging from 1 (*poor*) to 5 (*excellent*).

2.3. Analytic plan

We first examined the background characteristics of the study sample. We also performed bivariate analyses of daily volunteering and cortisol output, along with other daily covariates to examine whether involvement in volunteering was associated with daily characteristics.

The key research question was addressed using a series of multilevel models (2-level model), where observation days (level 1) were nested within persons (level 2). First, we examined the association between saliva cortisol output and daily stressors, as well as volunteering, controlling for all study covariates (i.e., daily and background characteristics; Model 1). In the subsequent model (Model 2), we examined the buffering effects of volunteering for the relationship between daily stressors and cortisol by introducing an interaction term between daily stressors and volunteering. The level 1 (*within-person*) equation for the multilevel model is as follows:

$$\text{Cortisol}_{ti} = b_{0i} + b_{1i}\,(\text{Daily stressor}_{ti}) + b_{2i}\,(\text{Daily volunteering}_{ti}) + b_{3i}\,(\text{Daily stressor}_{ti}) \times (\text{Daily volunteering}_{ti}) + b_{4i}\,(\text{Daily characteristics}_{ti}) + e_{ti},$$

where cortisol output is person *i*'s total cortisol output (calculated as AUC transformed by the natural log) on day *t*, b_{0i} is the individual specific intercept; b_{1i}, b_{2i}, and b_{3i} are the coefficients for daily stressors, daily volunteering, and the interaction terms, respectively. Daily covariates for person *i* on same day *t* (b_{4i}) were also added to the model as controls. For the effect size of the interaction term, we computed Cohen's *d* with reference to changes in the level-1 variance.

At level 2 (*between-person*), we added background characteristics to the model. Characteristics such as marital status, race, education level, self-rated health, and monthly volunteer status showed no statistically significant association with cortisol output and the inclusion of these variables in the models did not change the patterns of results for the other variables; therefore, these measures were dropped from the final models in the interest of parsimony. All analyses were performed using STATA; multilevel models were estimated using the XTMIXED procedure (Statacorp, 2013).

3. Results

Background characteristics of the study sample are presented in Table 1. On average, individuals in the sample reported providing about 12 h of volunteer work per month towards helping persons who are ill and young people, and less than an hour to volunteer work for a political cause. The majority of respondents were female (64%) and white (84%), with a high proportion the sample being married and having at least some college education. On average, the sample showed an above-normal body mass index, indicated good self-rated health, and woke up at around 6:30 in the morning.

Bivariate differences in cortisol output and other daily characteristics by daily volunteer status (i.e., volunteer day vs. non-volunteer day) are presented in Table 2. Volunteer days showed a lower level of cortisol output compared to non-volunteer days, although the difference was only marginally significant ($p = .09$). In general, other daily characteristics did not differ in relation to whether or not individuals volunteered on a given day.

Table 1
Background characteristics of study sample.

	M	(*SD*)
Age	52.46	(11.32)
Female, %	64.12	
Married, %	77.94	
White, %	84.41	
Working, %	70.00	
Education level, %		
Some high school/high school graduate	17.99	
Some college/college graduate	52.21	
Some graduate school and higher	29.79	
Body mass index (kg/m^2)	28.79	(13.14)
Self-rated health[a]	3.85	(0.89)
Wake time	6.57	(1.08)
Monthly volunteer hours		
Hospital, nursing home, other health-care-oriented work	8.84	(13.26)
School or other youth-related work	3.01	(7.18)
Political organizations or causes	0.57	(2.71)
Any other organizations, cause, or charity	5.23	(8.38)

Notes. Persons $N = 340$.
[a] Rated on a scale ranging from 1 (*poor*) to 5 (*excellent*).

Table 2
Daily characteristics by daily volunteer status.

	Days volunteered ($n = 169$)		Days not volunteered ($n = 873$)		*t* or χ^2
	M	(*SD*)	*M*	(*SD*)	
Total cortisol output (AUC)	125.58	(63.20)	134.58	(62.70)	2.91†
Any stressor, %	47.34		43.87		0.69
Total number of stressors	0.66	(0.79)	0.60	(0.79)	0.61
Wake time	6.53	(1.18)	6.52	(1.31)	0.00
Weekday, %	73.37		76.52		0.77

Notes. Persons $N = 340$; Person-day observations $N = 1{,}042$. AUC = Area Under the Curve with respect to the ground (nmol/l). Differences in daily characteristics by volunteer status were tested using *t*-tests for continuous variables and the chi-square statistic for categorical variables.
†$p < .10$.

Table 3
Multilevel model results for within-person associations of daily stress, volunteering, and cortisol output.

	Model 1		Model 2	
Fixed effects				
Intercept	4.79***	[4.64,4.95]	4.78***	[4.63,4.94]
Daily experiences				
Number of stressors	0.04*	[0.01,0.07]	0.05**	[0.02,0.09]
Volunteering	−0.01	[-0.08,0.06]	0.04	[-0.04,0.13]
× Number of stressors	–	–	−0.08*	[-0.15,-0.01]
Wake time	−0.09***	[-0.12,-0.06]	−0.09***	[-0.12,-0.06]
Had medication	−0.04	[-0.13,0.05]	−0.04	[-0.13,0.06]
Weekday	0.07*	[0.01,0.12]	0.07*	[0.01,0.13]
Background characteristics				
Age[a]	0.01**	[0.00,0.01]	0.01**	[0.00,0.01]
Female	−0.04	[-0.14,0.06]	−0.04	[-0.14,0.06]
Working	0.08	[-0.03,0.19]	0.08	[-0.02,0.19]
Body mass index[a]	0.00	[-0.01,0.00]	0.00	[-0.01,0.00]
Random effects				
Intercept variance	0.15***	[0.12,0.18]	0.15***	[0.12,0.18]
Residual variance	0.09***	[0.09,0.11]	0.09***	[0.08,0.10]
−2 log-likelihood	1,077.77		1,073.20	
AIC	1,101.77		1,099.20	

Notes. Persons $N = 340$; Person-day observations $N = 1{,}042$. Unstandardized coefficients and 95% confidence intervals (in parentheses). Cortisol output calculated as log-transformed of Area Under the Curve with respect to the ground.
*$p < .05$. **$p < .01$. ***$p < .001$.
[a] Grand mean-centered.

Results from the multilevel regression interaction models are presented in Table 3. In Model 1, number of daily stressors was associated with an increased level of cortisol output ($b = 0.04$, $p < .05$), holding other factors in the model constant. As expected, there was no relationship between daily volunteering and cortisol output. In Model 2, the effects of daily stressors on cortisol output was allowed to vary depending on daily volunteering with the inclusion of the interaction term between daily stressors and volunteering. As indicated by the statistically significant coefficient for the interaction term ($b = -0.08$, $p < .05$), we found support for the buffering effect of volunteering on the relationship between daily stressors and cortisol output. That is, the positive relationship between the number of daily stressors and cortisol output was weaker on days individuals were engaged in volunteer work compared to days not engaged in volunteering (see Fig. 1 for a graphic representation of the results from the multilevel model). The effect size of this buffering effect was relatively small ($d = 0.1$).

Regarding the relationships between the covariates and cortisol output, waking up late (compared to waking up early) was associated with a lower level of daily cortisol output and individuals showed

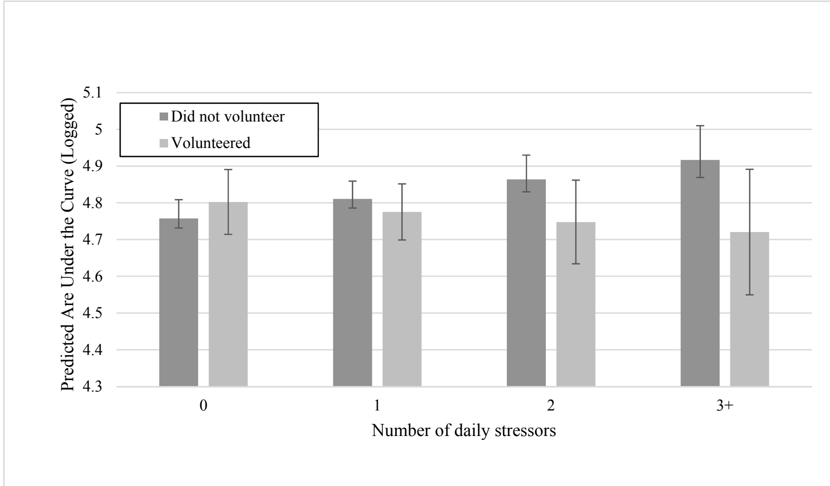

Fig. 1. Predicted saliva cortisol output, as calculated by log-transformed of Area Under the Curve with respect to the ground (and 95% confidence interval), by daily volunteer status for varying numbers of daily stressors, holding covariates constant at their mean values. The plots are based on estimated parameters from the multilevel models.

higher levels of cortisol output on weekdays compared to weekends. In addition, older adults showed a higher level of cortisol output compared to their younger counterparts.

4. Discussion

In this daily diary study framed within the neurobiological foundations of the caregiving system model (Brown and Brown, 2017; Brown and Cialdini, 2015), daily engagement in volunteer work was associated with reduced endocrine reactivity to stressors among a sample of middle-aged and older volunteers. This finding is in line with the stress-buffering effects of prosocial behavior on psychological health outcomes reported in a recent daily diary study based on a younger sample (mean age = 24.5; Raposa et al., 2016). The evidence for the stress-buffering effect of volunteering for salivary cortisol contributes to the small but growing body of scientific literature on the “under the skin” effects of volunteering (Burr et al., 2016; Kim and Ferraro, 2014; Nelson-Coffey et al., 2017). Importantly, our findings are suggestive of a unique health-promoting activity of volunteering; that is, helping behavior directed towards others in need may benefit the helper's health by dampening the adverse effects of stress, through the implicated (but not directly observed) activation of the caregiving system and health promoting hormones.

The principal finding that volunteer work attenuates the association between daily stressors and cortisol output on a daily basis provides empirical support for the CSM. Although we did not have the data to directly confirm the following, helping behavior directed towards other persons in need, implicated in our assumption that types of monthly volunteering is consistently replicated in daily volunteer activities, is likely to have been driven by the other-focused motivation, triggering the activation of the caregiving system and stress-buffering mechanisms (Brown and Cialdini, 2015). The interaction effect of daily volunteering and stressors for salivary cortisol output was consistently significant regardless of how stressors were measured (e.g., any stressors vs number of daily stressors) and the potential confounding factors controlled in the models, providing some confidence regarding the robustness of the results. Our findings based on observational daily dairy data provide initial evidence for hypothetical claims made in earlier studies with regards to how stress-buffering effects of prosocial behavior on mental and psychological health outcomes may have biological roots (Brown et al., 2008; Raposa et al., 2016). The small but significant stress-buffering effects of volunteering on salivary cortisol reported in this study should be taken as partial support for this idea, suggesting further studies aimed at better understanding the biological underpinnings of healthful effects of helping behavior.

Although we suspect that the buffering effects of volunteering reported in this study are associated with the caregiving system and secretion of OT, there are other potential explanations for this finding. First, the social bonds formed between the helper and the helped and the positive social interactions enabled through volunteer work (Piercy et al., 2011) may also contribute to the health-promoting neurobiological mechanisms (Heinrichs et al., 2009). As well, prosocial behaviors are shown to have an influence on the link between stressors and psychological health outcomes (Raposa et al., 2016), which can lead to differences in cortisol levels. Finally, the other-focused orientation inherent in some forms of volunteering may serve as a distraction from one's own sources of stress, thereby reducing the hormonal reactivity to stress (Midlarsky, 1991). For example, evidence from an experimental study indicated that individuals who experience acute social stress subsequently engaged in prosocial behavior, potentially as a coping mechanism (Dawans et al., 2012). Further research is needed to test these possible explanations.

4.1. Limitations

This study had several limitations. First, the NSDE did not provide information on the specific type of daily volunteer work performed; we therefore had to rely on volunteering status measured on a monthly basis from the main MIDUS study to infer the nature of daily volunteer work reported in the NSDE. Although the data limitations did not allow us to make any direct claims about the nature of daily volunteer work reported in the NSDE, we are able to make some indirect inferences based on the volunteer profiles of the study sample derived from the hours of monthly volunteering activity (see Table 1). That is, an average volunteer in the sample spent the majority of volunteering hours doing care-oriented work (i.e., health-care or youth-related volunteering) and less than an hour towards other purposes (e.g., political volunteering). Also, we make the strong assumption that the types of volunteering reported on a monthly basis are replicated for the types of volunteering reported on a daily basis, based on the significant consistency and continuity in volunteering activities reported among middle-aged and older adults. For example, research shows that two-year retention rates for volunteers in this age group, including volunteers for youth-related and health-care work, are around 70% (Foster-Bey et al., 2007). Regardless, some daily volunteer work reported in the NSDE is likely to be unrelated to other-focused helping behavior, although we believe that such measurement errors make the findings in our study conservative. Additional studies with specific volunteer activity on a daily basis are needed to confirm the results reported here.

Second, key neurobiological factors of the stress-buffering mechanism proposed in the CSM, including OT, were not evaluated in the analyses due to data limitations. Despite the difficulties in measuring OT in human subjects (McCullough et al., 2013), future studies should consider the link between OT, stress, and cortisol to corroborate the findings from this study, when data become available. Third, we are unable to confirm the temporal order between daily volunteer work and daily stressors; that is, we cannot ascertain whether stressors preceded or followed volunteer work. However, given the relatively long half-life of OT in the brain and the prolonged elevation of the hormone levels after initial release shown in recent studies (MacDonald and MacDonald, 2010; van Ijzendoorn et al., 2012), the proposed stress-buffering mechanism may hold even if volunteer activities followed an experience of daily stress. More research is needed here.

Finally, due to the limited availability of data from saliva samples in the NSDE, only 4 days of daily dairy data were used in the analyses, which likely resulted in capturing only a snapshot of the volunteer activities performed by the respondents. Although the small number of repeated observations (an average of 3.1 usable data points per respondent) are less desirable than daily diary study designs that include more observations, we engaged in supplementary analyses using more advanced analytic models, where within-person effects of daily stressors and volunteer activities are distinguished from between-person effects (Hoffman and Stawski, 2009). Results from these supplementary analyses were consistent with the main findings (see Supplementary Table 2.)

4.2. Contributions and future research directions

To the best of our knowledge, this study is the first to report the potential health benefits of formal volunteering using a daily dairy design, and our findings suggest that engaging in volunteer activities to help others in need may also help the helper's health. As well, the within-person analytic approach using a large sample of volunteers only allowed us to partly overcome the issue of social selection bias reported in earlier studies (Li and Ferraro, 2005) by comparing volunteer days to non-volunteer days while using individuals as their own controls. Although the observational nature of the study design does not allow us to discuss the findings in causal terms and clinical implications of these findings require careful interpretation, we believe that strong health benefits of care-oriented volunteering among middle-aged and older adults documented in earlier randomized control trials (e.g., Experience Corps) provide some confidence in the small but significant stress-buffering effects found in this study (Hong and Morrow-Howell, 2010). The results from the study uniquely demonstrate the stress-buffering effect of volunteering by using a biological stress marker (i.e., salivary cortisol output). Future studies should evaluate whether similar buffering effects exist for immediate health outcomes, using such measures as daily mood or daily physical symptoms. The stress-buffering effect reported herein is supportive of arguments found in earlier studies that call for providing volunteer opportunities as an intervention for individuals dealing with acute or chronic stress (Brown et al., 2008; Fried et al., 2004; Kim and Konrath, 2016; Li, 2007; Poulin and Holman, 2013). Finally, this study added to the growing empirical evidence in support of the CSM, and the results contribute to the neurobiological pathways that link health effects with prosocial behavior. Extending research efforts to examine stress-buffering effects for other forms of helping behavior, such as informal help provided to friends and caregiving given to family members (e.g., grandparenting; Hilbrand et al., 2017), would provide further insights into these complex processes.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.socscimed.2018.02.011.

References

Acabchuk, R.L., Kamath, J., Salamone, J.D., Johnson, B.T., 2017. Stress and chronic illness: the inflammatory pathway. Soc. Sci. Med. 185, 166–170. http://dx.doi.org/10.1016/j.socscimed.2017.04.039.

Almeida, D.M., Mcgonagle, K., King, H., 2009. Assessing daily stress processes in social surveys by combining stressor exposure and salivary cortisol. Biodemogr. Soc. Biol. 55 (2), 219–237. http://dx.doi.org/10.1080/19485560903382338.

Almeida, D.M., Piazza, J.R., Stawski, R.S., Klein, L.C., 2011. The speedometer of life: stress, health and aging. In: Schaie, K.W., Willis, S.L. (Eds.), Handbook of the Psychology of Aging. Acedemic Press, New York, pp. 191–206.

Almeida, D.M., Wethington, E., Kessler, R.C., 2002. The daily inventory of stressful events. Assessment 9 (1), 41–55. http://dx.doi.org/10.1177/1073191102091006.

Anderson, N.D., Damianakis, T., Kröger, E., Wagner, L.M., Dawson, D.R., Binns, M.A., The Bravo Team, 2014. The benefits associated with volunteering among seniors: a critical review and recommendations for future research. Psychol. Bull. 140 (6), 1505–1533. http://dx.doi.org/10.1037/a0037610.

Brim, O.G., Ryff, C.D., Kessler, R.C., 2004. How Healthy Are We? : a National Study of Well-being at Midlife. University of Chicago Press, Chicago, Il.

Brown, S.L., Brown, R.M., 2017. Compassionate neurobiology and health. In: Seppälä, E.M., Simon-Thomas, E., Brown, S.L., Worline, M.C., Cameron, C.D., Doty, J.R. (Eds.), The Oxford Handbook of Compassion Science. Oxford University Press, New York, NY.

Brown, S.L., Brown, R.M., House, J.S., Smith, D.M., 2008. Coping with spousal loss: potential buffering effects of self-reported helping behavior. Pers. Soc. Psychol. Bull. 34, 849–861. http://dx.doi.org/10.1177/0146167208314972.

Brown, S.L., Cialdini, R.B., 2015. Functional motives and functional consequences of prosocial behavior. In: Schroeder, D.A., Graziano, W.G. (Eds.), The Oxford Handbook of Prosocial Behavior. Oxford University Press, New York, pp. 346–361.

Burr, J.A., Han, S., Lee, H.J., Tavares, J.L., Mutchler, J.E., 2017. Health benefits associated with three helping behaviors: evidence for incident cardiovascular disease. J. Gerontol.: Series B. http://dx.doi.org/10.1093/geronb/gbx082. gbx082-gbx082.

Burr, J.A., Han, S.H., Tavares, J.L., 2016. Volunteering and cardiovascular disease risk: does helping others get "under the skin?". Gerontol 56 (5), 937–947. http://dx.doi.org/10.1093/geront/gnv032.

Dawans, B.V., Fischbacher, U., Kirschbaum, C., Fehr, E., Heinrichs, M., 2012. The social dimension of stress reactivity:Acute stress increases prosocial behavior in humans. Psychol. Sci. 23 (6), 651–660. http://dx.doi.org/10.1177/0956797611431576.

Foster-Bey, J., Dietz, N., Grimm, R., 2007. Keeping Baby Boomers Volunteering: a Research Brief on Volunteer Retention and Turnover. Corporation for National and Community Service.

Fried, L.P., Carlson, M.C., Freedman, M., Frick, K.D., Glass, T.A., Hill, J., Zeger, S., 2004. A social model for health promotion for an aging population: initial evidence on the experience corps model. J. Urban Health 81 (1), 64–78. http://dx.doi.org/10.1093/jurban/jth094.

Granger, D.A., Hibel, L.C., Fortunato, C.K., Kapelewski, C.H., 2009. Medication effects on salivary cortisol: tactics and strategy to minimize impact in behavioral and developmental science. Psychoneuroendocrinology 34 (10), 1437–1448. http://dx.doi.org/10.1016/j.psyneuen.2009.06.017.

Greenfield, E.A., Marks, N.F., 2004. Formal volunteering as a protective factor for older adults' psychological well-being. J. Gerontol. B Psychol. Sci. Soc. Sci. 59 (5), S258–S264. http://dx.doi.org/10.1093/geronb/59.5.S258.

Han, S.H., Tavares, J.L., Evans, M., Saczynski, J., Burr, J.A., 2017. Social activities, incident cardiovascular disease, and mortality. J. Aging Health 29 (2), 268–288. http://dx.doi.org/10.1177/0898264316635565.

Heinrichs, M., Von Dawans, B., Domes, G., 2009. Oxytocin, vasopressin, and human social behavior. Front. Neuroendocrinol. 30 (4), 548–557. http://dx.doi.org/10.1016/j.yfrne.2009.05.005.

Hilbrand, S., Coall, D.A., Meyer, A.H., Gerstorf, D., Hertwig, R., 2017. A prospective study of associations among helping, health, and longevity. Soc. Sci. Med. 187, 109–117. http://dx.doi.org/10.1016/j.socscimed.2017.06.035.

Hoffman, L., Stawski, R.S., 2009. Persons as contexts: evaluating between-person and within-person effects in longitudinal analysis. Res. Hum. Dev. 6 (2–3), 97–120. http://dx.doi.org/10.1080/15427600902911189.

Hong, S.I., Morrow-Howell, N., 2010. Health outcomes of experience corps®: a high-commitment volunteer program. Soc. Sci. Med. 71 (2), 414–420. http://dx.doi.org/10.1016/j.socscimed.2010.04.009.

Hostinar, C.E., Sullivan, R.M., Gunnar, M.R., 2014. Psychobiological mechanisms underlying the social buffering of the hypothalamic-pituitary-adrenocortical axis: a review of animal model and human studies across development. Psychol. Bull. 140 (1), 256–282. http://dx.doi.org/10.1037/a0032671.

Kim, E.S., Konrath, S.H., 2016. Volunteering is prospectively associated with health care use among older adults. Soc. Sci. Med. 149, 122–129. http://dx.doi.org/10.1016/j.socscimed.2015.11.043.

Kim, S., Ferraro, K.F., 2014. Do productive activities reduce inflammation in later life? Multiple roles, frequency of activities, and c-reactive protein. Gerontol 54 (5), 830–839. http://dx.doi.org/10.1093/geront/gnt090.

Krause, N., 2006. Church-based social support and mortality. J. Gerontol. B Psychol. Sci. Soc. Sci. 61 (3), S140–S146. http://dx.doi.org/10.1093/geronb/61.3.S140.

Kudielka, B.M., Kirschbaum, C., 2003. Awakening cortisol responses are influenced by health status and awakening time but not by menstrual cycle phase. Psychoneuroendocrinology 28 (1), 35–47. http://dx.doi.org/10.1016/S0306-4530(02)00008-2.

Kunz-Ebrecht, S.R., Kirschbaum, C., Marmot, M., Steptoe, A., 2004. Differences in cortisol awakening response on work days and weekends in women and men from the whitehall ii cohort. Psychoneuroendocrinology 29 (4), 516–528. http://dx.doi.org/10.1016/S0306-4530(03)00072-6.

Li, Y., 2007. Recovering from spousal bereavement in later life: does volunteer participation play a role? J. Gerontol. B Psychol. Sci. Soc. Sci. 62 (4), S257–S266. http://dx.doi.org/10.1093/geronb/62.4.S257.

Li, Y., Ferraro, K.F., 2005. Volunteering and depression in later life: social benefit or selection processes? J. Health Soc. Behav. 46 (1), 68–84. http://dx.doi.org/10.1177/002214650504600106.

MacDonald, K., MacDonald, T.M., 2010. The peptide that binds: a systematic review of oxytocin and its prosocial effects in humans. Harv. Rev. Psychiatr. 18 (1), 1–21. http://dx.doi.org/10.3109/10673220903523615.

McCullough, M.E., Churchland, P.S., Mendez, A.J., 2013. Problems with measuring peripheral oxytocin: can the data on oxytocin and human behavior be trusted? Neurosci. Biobehav. Rev. 37 (8), 1485–1492. http://dx.doi.org/10.1016/j.neubiorev.2013.04.018.

Midlarsky, E., 1991. Helping as Coping *Prosocial Behavior*. Sage Publications, Inc, Thousand Oaks, CA, US, pp. 238–264.

Morrow-Howell, N., 2010. Volunteering in later life: research frontiers. J. Gerontol. B Psychol. Sci. Soc. Sci. 65B (4), 461–469. http://dx.doi.org/10.1093/geronb/gbq024.

Müller, D., Ziegelmann, J.P., Simonson, J., Tesch-Römer, C., Huxhold, O., 2014. Volunteering and subjective well-being in later adulthood: is self-efficacy the key? Int. J. Dev. Sci. 8 (3–4), 125–135. http://dx.doi.org/10.3233/DEV-14140.

Mutchler, J.E., Burr, J.A., Caro, F.G., 2003. From paid worker to volunteer: leaving the paid workforce and volunteering in later life. Soc. Forces 81 (4), 1267–1293. http://dx.doi.org/10.1353/sof.2003.0067.

Nelson-Coffey, S.K., Fritz, M.M., Lyubomirsky, S., Cole, S.W., 2017. Kindness in the blood: a randomized controlled trial of the gene regulatory impact of prosocial behavior. Psychoneuroendocrinology 81, 8–13. http://dx.doi.org/10.1016/j.psyneuen.2017.03.025.

Piazza, J.R., Almeida, D.M., Dmitrieva, N.O., Klein, L.C., 2010. Frontiers in the use of biomarkers of health in research on stress and aging. J. Gerontol. B Psychol. Sci. Soc. Sci. 65 (5), 513–525. http://dx.doi.org/10.1093/geronb/gbq049.

Piercy, K.W., Cheek, C., Teemant, B., 2011. Challenges and psychosocial growth for older volunteers giving intensive humanitarian service. Gerontol 51 (4), 550–560. http://dx.doi.org/10.1093/geront/gnr013.

Poulin, M.J., 2014. Volunteering predicts health among those who value others: two national studies. Health Psychol. 33 (2), 120–129. http://dx.doi.org/10.1037/a0031620.

Poulin, M.J., Holman, E.A., 2013. Helping hands, healthy body? Oxytocin receptor gene and prosocial behavior interact to buffer the association between stress and physical health. Horm. Behav. 63 (3), 510–517. http://dx.doi.org/10.1016/j.yhbeh.2013.01.004.

Pruessner, J.C., Kirschbaum, C., Meinlschmid, G., Hellhammer, D.H., 2003. Two formulas for computation of the area under the curve represent measures of total hormone concentration versus time-dependent change. Psychoneuroendocrinology 28 (7), 916–931. http://dx.doi.org/10.1016/S0306-4530(02)00108-7.

Raposa, E.B., Laws, H.B., Ansell, E.B., 2016. Prosocial behavior mitigates the negative effects of stress in everyday life. Clinical Psychological Science 4 (4), 691–698. http://dx.doi.org/10.1177/2167702615611073.

Statacorp, 2013. Stata Statistical Software: Release 13. StataCorp LP, College Station, TX.

Stawski, R.S., Cichy, K.E., Piazza, J.R., Almeida, D.M., 2013. Associations among daily stressors and salivary cortisol: findings from the national study of daily experiences. Psychoneuroendocrinology 38 (11), 2654–2665. http://dx.doi.org/10.1016/j.psyneuen.2013.06.023.

Thoits, P.A., 2010. Stress and health: major findings and policy implications. J. Health Soc. Behav. 51 (1_Suppl. l), S41–S53. http://dx.doi.org/10.1177/0022146510383499.

Thoits, P.A., Hewitt, L.N., 2001. Volunteer work and well-being. J. Health Soc. Behav. 42 (2), 115–131. http://dx.doi.org/10.2307/3090173.

van Ijzendoorn, M., Bhandari, R., van der Veen, R., Grewen, K., Bakermans-Kranenburg, M., 2012. Elevated salivary levels of oxytocin persist more than 7 h after intranasal administration. Front. Neurosci. 6 (174). http://dx.doi.org/10.3389/fnins.2012.00174.