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Research Article

Functional Limitations, Volunteering, and Diurnal Cortisol Patterns in Older Adults

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Abstract

Objectives: Older adults often experience functional limitations that affect their everyday lives, but many of them continue to make positive contributions to society and benefit from these contributions themselves. We examine (a) whether older adults' functional limitations are associated with diurnal cortisol patterns and (b) whether these associations vary on volunteering days versus nonvolunteering days.
Methods: Participants were adults aged older than 60 years (N = 435) from the *National Study of Daily Experiences*, part of the *Midlife in the United States Study*. They completed an initial interview on functional limitations and background characteristics, indicated volunteering activities in daily interviews, and also provided salivary samples across 4 days.
Results: Multilevel models showed that older adults with greater functional limitations exhibited dysregulated cortisol awakening responses and diurnal cortisol slopes throughout the rest of the day, compared to older adults with lower limitations. Yet, we also observed a significant moderating effect of volunteering on these associations.
Discussion: This study advances our understanding of functional limitations and cortisol stress responses, revealing the benefits of volunteering to older adults who experience these limitations. Rather than treating these older adults solely as care recipients, interventions should offer them opportunities to help others.

Keywords: Cortisol, Functional limitations, National Study of Daily Experiences, Volunteering

Functional limitations become more prevalent as people age and can be a major source of chronic stress for older adults (Barry et al., 2009; Chatterji et al., 2015). These limitations are typically reflected in older adults' restricted abilities to perform activities (e.g., bathing, toileting, and dressing) required for living independently in the community. Research has linked functional limitations to increased psychological distress (Gayman et al., 2008). It is less clear, however, how the burden of these limitations gets under the skin. To answer this research question, the current study assesses whether older adults' functional limitations are associated with their diurnal cortisol patterns, which reflect physiological stress responses. We examine older adults with varying levels of functional limitations, including those who have no limitation.

Cortisol, a stress hormone produced by the hypothalamic–pituitary–adrenal (HPA) axis, has been linked to individuals' responses to daily and chronic life stress (Adam et al., 2017; Wilhelm et al., 2007). Cortisol follows a diurnal rhythm. Each day, it increases and peaks around 30–45 min after waking (cortisol awakening response [CAR]), which is part of healthy circadian physiology that prepares individuals for the upcoming day (Fries et al., 2009; Powell & Schlotz, 2012; Stalder et al., 2016). The hormone then steadily declines throughout the day until bedtime (diurnal cortisol slope [DCS]). Flattened CAR and DCS both reflect dysregulated HPA axis responses, which are often observed in individuals under chronic stress (e.g., Powell & Schlotz, 2012; Strahler et al., 2010).

We aim to better understand functional limitations and dysregulated cortisol responses by asking whether the associations vary on a daily basis depending on older adults' engagement in volunteering. Although older adults with functional limitations are predominantly viewed as recipients of care (Bangerter et al., 2017; Kim et al., 2017), they may also offer and benefit from offering help (Boerner & Reinhardt, 2003; Huo et al., 2018). This study focuses on volunteering, defined as a prosocial behavior performed under auspices of a formal organization to benefit people outside their social networks at no compensation (Brown & Brown, 2017; Wilson, 2000). Research suggests that volunteering yields psychological benefits and buffers against stress, which may aid HPA axis regulation (Anderson et al., 2014; Han & Hong, 2013; Thoits, 2012). Furthermore, due to the formal nature of volunteering, it is more often prearranged than other helping behaviors that also occur on a daily basis (e.g., informally helping family, friends, or neighbors). A focus on volunteering uniquely allows us to examine whether the prospect of helping others during the upcoming day influences older adults' cortisol responses upon waking (i.e., CAR).

Functional Limitations and Daily Cortisol Patterns

Functional limitations in performing activities of daily living are a common source of chronic stress in late life (Barry et al., 2009; Charles, 2010). Almeida (2005) put forth a model on how individual health factors such as functional limitations may influence their exposure and reactivity to daily stressors. Having greater functional limitations often results in dependence on others and reduced self-esteem, which exposes older adults to psychological distress (Mullen et al., 2012; Shaw et al., 2010; Wagner et al., 2013). Over time, repeated exposure to such stressors can lead to disruptions in maintaining homeostasis (Herman et al., 2016).

Research has demonstrated how physical declines (often a precursor of functional limitations) influence cortisol patterns. Varadhan et al. (2008) tracked cortisol patterns in 214 frail women aged 80–89. They found frailer older women had smaller declines in cortisol during morning hours (after reaching the peak post-waking) and higher levels of evening cortisol levels. Ryan et al. (2017) found older patients suffering breathlessness showed flatter cortisol declines throughout the day compared to healthy controls. A meta-analysis revealed older adults with poorer physical performance (e.g., standing balance and walking) exhibited flattened CAR and smaller cortisol drops than older adults with good physical performance (de Albuquerque Sousa et al., 2017; Gardner et al., 2013). Consequently, in the current study, we hypothesize that greater functional limitations will be associated with flattened CAR and DCS.

The Moderating Role of Volunteering

A plethora of empirical evidence documents the psychosocial and physiological benefits of volunteering in later life (Anderson et al., 2014; Brown & Brown, 2017). This study builds on prior research and asks whether engaging in daily volunteer work exerts a protective influence on older adults with functional limitations. Although these older adults are less likely to volunteer than their healthy counterparts (Li & Ferraro, 2006; Principi et al., 2016), little is known about whether volunteering on certain days explains within-person variation in cortisol patterns. We address this gap by examining whether older adults with functional limitations will exhibit less dysregulated cortisol patterns on volunteering days compared to nonvolunteering days.

This study investigates the moderating effect of volunteering on both CAR and DCS. Several theoretical perspectives guide our hypotheses. The enhanced allostasis model links psychological benefits to HPA axis restoration (Bower et al., 2008). Volunteering offers older adults with functional limitations a unique opportunity to obtain psychological benefits regularly, which may explain how *the prospect of volunteering* influences these older adults' stress responses when they start the day (i.e., CAR). We also expect that *the act of volunteering* would help attenuate the dysregulated cortisol declines during the day (i.e., DCS) among older adults with functional limitations. This hypothesis is grounded in the caregiving system model, which provides a promising neurobiological explanation for positive health outcomes associated with prosocial behaviors (Brown & Brown, 2017).

Volunteering and CAR

Being a volunteer has been traditionally considered a desirable social role for older adults. It serves as an important source of purpose in life, personal growth, and positive social experiences (Gruenewald et al., 2007; Han & Hong, 2013; Piercy et al., 2011; Thoits, 2012), which are often compromised in older adults with functional limitations. Although volunteering may be challenging for these older adults (Li & Ferraro, 2006), it is likely an adaptive challenge that they look forward to (Han et al., 2019). One of the key functions of CAR is to prepare individuals for challenges of the upcoming day, such that individuals show increased CAR on days when they anticipate a more challenging day than usual (Fries et al., 2009). Thus, we ask whether older adults with greater functional limitations will show relatively less flattened or even steeper CAR in the mornings when they anticipate volunteering.

Volunteering and DCS

Engaging in volunteer work may also influence older adults' daily cortisol declines. The caregiving system model illustrates a mechanism in the brain that promotes prosocial behavior by inhibiting self-serving motivations and increasing other-focused motivations (Brown & Brown, 2017; Brown & Okun, 2014). This mechanism involves a stress regulatory process partly facilitated by hormonal correlates of the caregiving system (e.g., oxytocin). Both animal and human studies have shown that these hormones regulate HPA axis activity and influence stress-induced cortisol levels (Heinrichs et al., 2009; Hostinar et al., 2014). Prior research has demonstrated how volunteering alleviates hormonal and affective reactivity to minor stressors older adults experience on a daily basis (Han et al., 2018, 2019). We extend this line of research by conducting the first study that examines whether volunteering on certain days exerts similar protective effects in the context of chronic stress, such as functional limitations older adults experience. We expect less flattened or steeper DCS on volunteering days compared to nonvolunteering days among older adults with greater functional limitations.

Other Factors as Covariates

We adjusted for additional factors that are associated with older adults' functional limitations, volunteering, and cortisol patterns. We considered demographic characteristics (i.e., age, gender, education, racial/ethnic minority status, relationship status, and caregiver status), health and health behavior characteristics (i.e., body mass index, medication use, and smoker status), and daily characteristics (i.e., wake time, daily stressors, and daily working for pay). Research has documented an age-related increase in functional limitations (Chatterji et al., 2015). Older women are more likely to report functional limitations than men (Crimmins et al., 2011) and they are typically more reactive to stress (Saxbe et al., 2008). Research has also documented racial differences in cortisol patterns (Hajat et al., 2010). Partnered individuals are more likely to start and less likely to stop volunteering (Butrica et al., 2009); a growing body of research has also linked being married or cohabitating to diurnal cortisol levels (Sharpley et al., 2019). We also adjusted for older adults' caregiver status to consider the effect of other helping behaviors than volunteering on cortisol patterns among older adults. Body mass index has been linked to elevated cortisol levels (Champaneri et al., 2013). We also included medication use, smoking, and wake time that are commonly included in cortisol research; for example, wake time serves as a proxy of older adults' sleep patterns that may vary by their limitations (Adam et al., 2017; Stawski et al., 2013). Daily stressors were included given their influence on cortisol, as well as to control for role strain experienced among people who have multiple social roles (e.g., caregiving and working) on a given day (Thoits, 2012). Lastly, we adjusted for daily working for pay to consider that some older adults may still be in the paid labor force, which likely influences their daily cortisol patterns and engagement in volunteer work (Morrow-Howell, 2010).

This study examines functional limitations, volunteering, and diurnal cortisol patterns in older adults. We expect older adults with greater functional limitations to show flattened CAR and DCS than older adults with lower or no limitations. We also expect these links to vary on a daily basis, depending on whether older adults volunteer that day.

Method

Data and Study Sample

This study drew data from the second wave of the *National Study of Daily Experiences* (NSDE II; Almeida et al., 2009), which is a random subsample of the *Midlife in the United States* (MIDUS II; Brim et al., 2004). NSDE included 2,022 participants (age range: 35–84) who completed an initial interview as part of MIDUS and also daily diary telephone interviews across 8 consecutive days. On 4 consecutive days during the observation period, participants provided four saliva samples throughout the day (i.e., upon waking, 30 min after getting out of bed, before lunch, and at bedtime; for detailed information on the NSDE II, see the study of Almeida et al., 2009).

The purpose of this study was to examine older adults' functional limitations, volunteering, and diurnal cortisol patterns. Thus, we constrained our sample to NSDE participants aged 60 and older who provided saliva samples. Of the 2,022 NSDE participants, 796 were 60 or older (39%); 688 of these older adults (86%) provided saliva samples during the observation period. In accordance with the strict criteria recommended for cortisol analyses (Dmitrieva et al., 2013; Piazza et al., 2018), data were only retained in our analyses if participants complied with the saliva collection protocol and the cortisol levels were within the normal range (i.e., <60 nmol/L). Daily data were excluded if participants reported that (a) they were awake for less than 12 h or more than 20 h during the day, (b) reported less than 15 min or more than 60 min between the first (i.e., upon waking) and second (i.e., 30 min after getting out of bed) saliva samples, or (c) they had irregular daily schedules (i.e., nightshift workers). The criteria yielded 467 participants with 1,435 person-day observations. Finally, participants with missing information on functional limitations (n = 12), body mass index (n = 29), or caregiver status (n = 1) were also excluded from the study. None of the daily measures had missing data. The final analytic sample included 435 participants who provided 1,346 daily reports (Table 1).

Measures

Initial interview measures in MIDUS

Functional limitations

Participants rated how much health limited them from doing the following activities: (a) bathing or dressing themselves, (b) climbing one flight of stairs, and (c)

Table 1. Background Characteristics of the Study Sample

Variable	*M*	(*SD*)	Range
Functional limitations[a]	1.45	(0.72)	1–4
Age	68.29	(6.37)	60–84
Body mass index (kg/m^2)	28.07	(5.23)	15–35
	Proportion		
Female	0.57		
Married or cohabitating	0.70		
White	0.87		
Education level			
Some high school/high school graduate	0.37		
Some college/college graduate	0.45		
Some graduate school and higher	0.18		
Caregiver	0.15		
Current smoker	0.08		
Uses at least one medication	0.42		

Note: Participant *N* = 435.
[a]Rated from 1 = *not at all* to 4 = *a lot*.

walking one block. The response was coded on a 4-point scale from 1 (*not at all*) to 4 (*a lot*). We created a mean score across items, with higher scores indicating greater functional limitations.

Background covariates
Participants provided age (in years), gender coded as 1 (*female*) or 0 (*male*), and education level coded from 1 (*some high school/high school graduate*), 2 (*some college/college graduate*) to 3 (*some graduate school or above*), which was then dummy coded with the high school category as the reference group. Participants self-identified their racial/ethnic groups, which was recoded to 1 (*non-Hispanic whites*) or 0 (*minorities*). Self-reported relationship status was recoded to 1 (*married/cohabitating*) or 0 (*not married/cohabitating*). In this sample, about 5% of nonmarried participants were cohabitating with someone in a marriage-like relationship. Participants also indicated whether they had given personal care for a period of 1 month or more to a family member or friend because of a physical or mental condition, illness, or disability, which reflected their caregiver status coded as 1 (*caregiver*) or 0 (*noncaregiver*). Health and health behavior characteristics included body mass index (in kg/m^2), smoking status coded as 1 (*current smoker*) or 0 (*nonsmoker*), and medication use (e.g., allergy medications, steroid inhaler, steroid medications, cortisone, birth control pills, other hormones, antidepressants, and anxiety medications) recoded as 1 (*at least one medication*) or 0 (*no medication*).

Daily measures

Daily cortisol measures
We analyzed CARs and DCSs, using saliva samples collected at three time points each day (S1: upon waking; S2: 30 min after getting out of bed; S3: bedtime). CAR was calculated for each participant each day by subtracting the raw values of S1 from S2. DCS was calculated by subtracting S2 from S3, hence resulting in a negative value. For both CAR and DCS, greater *absolute* values denote steeper changes in cortisol levels.

The issues below regarding the measurement of diurnal cortisol patterns merit a mention. CAR is one of the two components that underlie the physiology of postawakening cortisol secretion, with the other component being the initial level of cortisol level upon waking (i.e., raw value of S1). Researchers suggest adjusting for the initial level of cortisol (S1) in analyses of CAR (Stalder et al., 2016) and we followed this suggestion in a sensitivity analysis. This analysis revealed similar patterns to the main findings reported in the *Results* section. With regard to the calculation of DCS, we utilized the peak-to-bed approach, in which peak refers to the time point at 30 min after waking (S2; Adam et al., 2017). Compared to a number of other approaches, this approach provided a better measure for differences in diurnal cortisol patterns across individuals with varying degrees of functional limitations.

Daily volunteering
Participants indicated their involvement in formal volunteering on a given day by answering "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?" Responses were coded as 1 (*yes*) or 0 (*no*).

Daily covariates
Daily covariates included daily stressors, wake time, and working for pay (Stalder et al., 2016). Participants indicated exposures to various types of stressors during the past day using the 8-item Daily Inventory of Stressful Events index (Almeida et al., 2002). Because participants reported more than three stressors on less than 1% of the study days, the measure was top-coded at three, with higher scores indicating more exposure to daily stressors for a given day (range: 0–3). Participants self-reported time of awakening each day, with higher values indicating later wake time (Kudielka & Kirschbaum, 2003). Participants indicated how much time they spent on activities related to business, paid work, or school (including travel time and time spent looking for work). We were interested in whether participants were involved in paid work each day. Thus, we recoded this variable so that a nonzero-hour response was coded as 1 (*working for pay this day*) and a zero-hour response or an answer of "don't know/inapplicable" was coded as 0 (*not working for pay this day*).

Analytic Plan

The key research questions concern the associations between functional limitations, volunteering, and diurnal cortisol patterns in older adults. We tested our hypotheses using multilevel models, where days (*Level 1*) were nested within persons (*Level 2*). We used a within–between random-effects modeling approach so that each time-varying variable (i.e., daily characteristics) was decomposed into a between-person (BP; Level 2; person-mean across days) and a within-person (WP; Level 1; deviation from the person-mean at a given day) components. This approach avoided convergence effect of the Level-1 effect of the time-varying predictor, as well as the cross-level interaction effect involving Level-1 (e.g., daily volunteering) and Level-2 (e.g., functional limitations) predictors that assume equivalence of WP and BP effects (Schunck, 2013). We estimated all models using the MIXED procedure in STATA 15.1. All models controlled for participant age, gender, education, racial/ethnic minority status, relationship status, caregiver status, body mass index, smoker status, medication use, daily wake time, daily stressors, and daily working for pay.

We first examined whether older adults' functional limitations were associated with CAR and DCS, in two models. We then tested whether daily volunteering moderated these associations by introducing a cross-level interaction term. The shorthand version of the multilevel moderation model equation is as follows:

$$
\begin{aligned}
\text{Diurnal cortisol}_{ti} = \gamma_{00} &+ \gamma_{01}\,(\text{Functional limitations}_i) \\
&+ \gamma_{10}\,(\text{WP: Daily volunteering}_{ti}) \\
&+ \gamma_{11}\,(\text{Functional limitations}_i) \times (\text{WP: Daily volunteering}_{ti}) \\
&+ \gamma_{20}\,(\text{WP: Daily characteristics}_{ti}) \\
&+ \gamma_{02}\,(\text{BP: Daily volunteering}_i) \\
&+ \gamma_{03}\,(\text{BP: Daily characteristics}_i) \\
&+ \gamma_{04}\,(\text{Background characteristics}_i) \\
&+ u_{0i} + e_{ti,}
\end{aligned}
$$

where cortisol is person *i*'s cortisol outcome (CAR or DCS) on day *t*, γ_{00} is the individual-specific intercept; γ_{01}, γ_{10}, and γ_{11} are the coefficients for functional limitations, daily volunteering, and the interaction terms, respectively. We further examined significant interaction effects with simple slopes analysis.

Results

Table 1 presents the background characteristics of the sample, and Table 2 describes daily characteristics. Among the 435 participants, 40% (n = 173) had at least one functional limitation to some extent, with the other 262 participants assigning 1 (*not at all*) to all limitation items. These participants were older, more likely to be female, less educated, more likely to use medications, and reported greater body mass index than their counterparts without any functional limitation. Furthermore, of the 173 participants who reported some functional limitations, 37 participants (21%) volunteered at least once and they volunteered for 1.40 days on average. We present bivariate correlations among all variables of interest in Supplementary Table 1.

Table 2. Daily Characteristics of the Study Sample

Variable	*M*	(*SD*)
Raw cortisol values (nmol/L)		
Upon waking (S1)	15.06	(8.83)
30 min after getting out of bed (S2)	22.35	(11.82)
Bedtime (S3)	3.51	(4.44)
Cortisol awakening responses[a]	7.28	(11.60)
Diurnal cortisol slopes[b]	−18.84	(12.22)
Daily volunteering[c]	0.11	
Daily stressors[d]	0.40	(0.63)
Daily wake time	6.51	(1.31)
Work day[e]	0.24	

Note: Participant N = 435; person-day observation N = 1,346.
[a]Calculated as S2–S1.
[b]Calculated as S3–S2.
[c]Proportion of days participants volunteered.
[d]Average number of stressors encountered daily (range: 0–3).
[e]Proportion of days participants worked for pay.

Functional Limitations and Cortisol Patterns

We hypothesized that older adults' functional limitations will be associated with CAR and DCS. As expected, multilevel models revealed that participants with greater functional limitations showed flattened CAR (B = −1.27, p = .032; see Model 1A in Table 3) and DCS (B = 1.78, p = .014; see Model 1B in Table 3) than participants with lower functional limitations.

The Moderating Role of Volunteering

We also expected these links between functional limitations and diurnal cortisol patterns to vary depending on whether older adults volunteered on certain days. That is, we hypothesized that older adults with greater limitations would show steeper DCS and less flattened CAR on volunteering days than nonvolunteering days. As expected, we observed significant moderating effects of volunteering on the associations of older adults' functional limitations with CAR (B = 4.45, p = .042; see Model 2A in Table 3) and DCS (B = −5.71, p = .003; see Model 2B in Table 3). We present simple slopes analyses for the moderation effects in Figure 1. Older adults with at least some functional limitations showed steeper CAR on volunteering days than nonvolunteering days. Yet, CAR did not vary in relation to daily volunteering status among older adults with no or a little functional

Table 3. Multilevel Models for Associations Between Functional Limitations and Diurnal Cortisol Patterns

	CAR				DCS			
	Model 1A		Model 2A		Model 1B		Model 2B	
Variable	*B*	(*SE*)	*B*	(*SE*)	*B*	(*SE*)	*B*	(*SE*)
Fixed effects								
Intercept	7.22**	(2.65)	7.22**	(2.65)	−13.77***	(3.23)	−13.77***	(3.23)
Functional limitations[a]	−1.27*	(0.59)	−1.27*	(0.59)	1.78*	(0.73)	1.78*	(0.73)
× Daily volunteering (within-person)	—		4.45*		—		−5.71**	(1.93)
Daily volunteering (within-person)	0.34	(1.24)	0.96	(1.27)	−1.97	(1.10)	−2.76*	(1.12)
Daily characteristics								
Within-person effects								
Daily stressors	0.43	(0.61)	0.43	(0.61)	−0.99	(0.54)	−0.99	(0.54)
Wake time	−0.72	(0.48)	−0.69	(0.48)	0.54	(0.42)	0.51	(0.42)
Work day	−0.51	(1.12)	−0.59	(1.12)	0.20	(0.99)	0.30	(0.99)
Between-person effects								
Daily volunteering	−0.30	(1.73)	−0.30	(1.73)	0.09	(2.11)	0.09	(2.11)
Daily stressors	0.86	(0.89)	0.86	(0.89)	−1.21	(1.06)	−1.21	(1.06)
Wake time[a]	0.08	(0.34)	0.08	(0.34)	−0.49	(0.41)	−0.49	(0.41)
Work day	0.40	(1.18)	0.40	(1.18)	−0.21	(1.44)	−0.21	(1.44)
Background characteristics								
Age[a]	0.18**	(0.07)	0.18**	(0.07)	−0.12	(0.08)	−0.12	(0.08)
Female	0.77	(0.85)	0.77	(0.85)	0.59	(1.04)	0.59	(1.04)
Married or cohabitating	0.64	(0.94)	0.64	(0.94)	0.28	(1.15)	0.28	(1.15)
White	−1.40	(1.20)	−1.41	(1.20)	−2.77	(1.47)	−2.77	(1.47)
Education[b]								
Some college/college graduate	−1.23	(0.86)	−1.23	(0.86)	0.41	(1.06)	0.41	(1.06)
Some graduate school and higher	−1.17	(1.15)	−1.17	(1.15)	0.61	(1.41)	0.61	(1.41)
Caregiver	0.02	(1.08)	0.02	(1.08)	−0.10	(1.33)	−0.09	(1.33)
Body mass index[a]	0.13	(0.08)	0.13	(0.08)	−0.01	(0.10)	−0.01	(0.10)
Current smoker	0.96	(1.46)	0.96	(1.46)	0.44	(1.80)	0.43	(1.80)
Medication use	0.30	(0.81)	0.30	(0.81)	0.84	(1.00)	0.84	(1.00)
Random effects								
Intercept variance (*Level 2*)	26.62***	(4.57)	26.79***	(4.57)	64.66***	(6.70)	64.99***	(6.70)
Residual variance (*Level 1*)	105.66***	(4.95)	105.18***	(4.95)	82.77***	(3.91)	81.97***	(3.88)
−2 log-likelihood	10,338.34		10,334.20		10,284.44		10,275.76	

Notes: Participant *N* = 435; person-day observation *N* = 1,346. CAR = cortisol awakening response; DCS = diurnal cortisol slope.
[a]Grand mean-centered.
[b]Reference category = some high school/high school graduate.
$^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

limitation. Older adults with at least a little functional limitation exhibited steeper DCS on volunteering days than on nonvolunteering days. DCS did not vary by daily volunteering status among older adults with no functional limitation.

Discussion and Implications

This study aims to understand whether older adults' functional limitations, as a key source of chronic stress in late life, place physiological burdens on them and whether volunteering provides a daily buffer against these limitations. As expected, we found older adults with greater functional limitations exhibited flattened diurnal cortisol responses than their counterparts with lower or no limitations. Yet, diurnal cortisol patterns were less dysregulated on days when older adults volunteered compared to nonvolunteering days, suggesting a possible normalizing effect of volunteering. Findings make a unique contribution to the literature by considering older adults with functional limitations as potential providers of help and offer new insights into designing interventions that could benefit this population.

Functional Limitations and Cortisol Patterns

Our findings from daily data demonstrate a unique physiological stress response mechanism underlying older

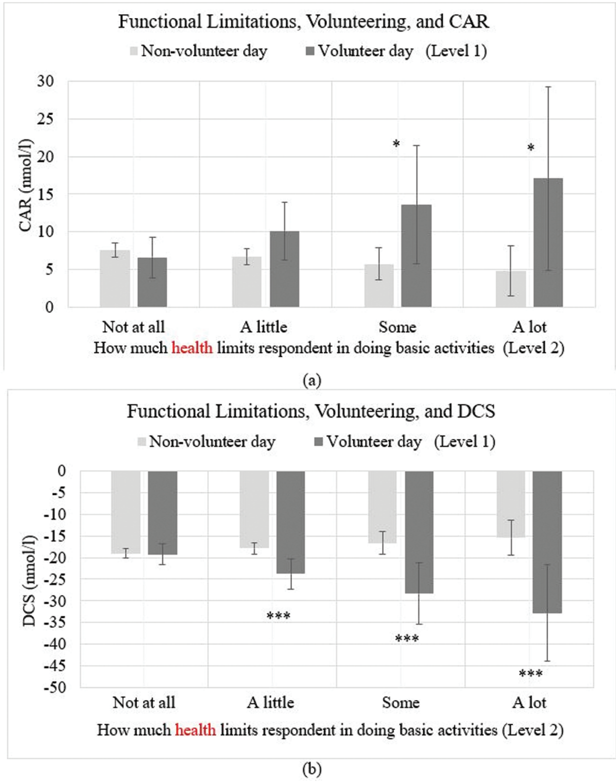

Figure 1. Interaction effects of functional limitations and daily volunteering on older adults' diurnal cortisol patterns: (A) cortisol awakening response (CAR) and (B) diurnal cortisol slope (DCS). $*p < .05$, $***p < .001$. The significance refers to a statistical difference between nonvolunteer days and volunteer days at a given level of functional limitations.

adults' functional limitations. As expected, older adults' functional limitations were associated with flattened CARs and DCSs, suggestive of dysregulated HPA axis functioning. Older adults with greater functional limitations likely wake up less prepared to meet the challenges in the upcoming day (Fries et al., 2009; Powell & Schlotz, 2012), and they may spend the rest of the day showing maladaptive responses to stressors (Adam et al., 2017). Some research has found that older adults who show elevated cortisol secretion are more likely to develop functional limitations later (Piazza et al., 2018; Wrosch et al., 2009). There may be a vicious cycle of functional limitations and dysregulated cortisol patterns, but a test of this cycle requires longitudinal data in future research.

It is worth noting that this study did not assess the specific stressors that older adults with functional limitations may encounter in their everyday lives. According to the exposure-reactivity model (Almeida, 2005), older adults' functional limitations may be a source of both chronic stressors and also acute stressors. Future research may explicitly ask these older adults to report on what bothers them in their everyday lives.

The Moderating Role of Volunteering

As expected, we found that volunteering benefitted older adults with greater functional limitations by helping to normalize their dysregulated cortisol patterns. This finding offers suggestive evidence for the caregiving system model (Brown & Brown, 2017) and is in line with a prior study that views volunteering as a stress buffer for older adults with functional limitations. Okun et al. (2010) tracked older adults for 6 years and found that volunteering reduced the link between functional limitations and mortality. Neither the study by Okun et al. nor our study tested functional limitation-related chronic stress explicitly.

It is also worth noting that the links between functional limitations and diurnal cortisol patterns are somewhat intensified in the opposite direction on volunteering days, which seems to reflect an effect that is more than normalizing. It is possible that volunteering is a more stimulating daily event for older adults with functional limitations than their healthy counterparts. The former thus experience a more intense neurohormonal cascade when they anticipate demands of volunteering in the upcoming day as well as when they engage in such volunteering. Thus, it is crucial to consider the workload of volunteering opportunities provided to older adults based on their levels of functional limitations. Further investigations are needed.

Our finding also advances our understanding of the link between volunteering and functional limitations in late life (Carr et al., 2018; Li et al., 2013). It is possible that volunteering attenuates the vicious cycle of older adults' functional limitations and dysregulated cortisol patterns on a daily basis (as elaborated above), which may slow down the disablement process over time. Nevertheless, the mechanism underlying this possible explanation remains unclear. It is worth reiterating that older adults' propensity to perform different types of volunteer work depends on their health and level of functional limitations. As such, older volunteers with functional limitations may benefit more by engaging in volunteer tasks that are less physically intensive and more socially engaging. Future studies may clarify the volunteering-health nexus by focusing on the intersections between the health of the volunteer, type and intensity of the volunteer work, and health outcomes.

Furthermore, we add to the burgeoning literature that identifies how older adults with functional limitations may benefit from helping others. Huo et al. (2018) found that helping adult children may be rewarding to older parents with functional limitations, suggesting that helping perhaps alleviate older parents' distress over their limitations. The current study directly tested stress responses in older adults with functional limitations and suggests volunteering may restore their HPA axis stress regulation. We are not able to test whether factors such as sense of purpose and hormonal correlates underlie these links due to data limitations. Future studies may explicitly test whether volunteering compensates for the reduced self-esteem among older adults with functional limitations and whether such compensation is key to the restoration of these older adults' HPA axis regulation.

Limitations and Implications

Several additional limitations to this study warrant consideration. We drew on 4 days of data due to the limited availability of cortisol samples collected in the NSDE. Future research may collect data for more days, which may reveal greater variability in older adults' volunteering and cortisol patterns. This sample did not report severe functional limitations. Volunteering may require extra effort and be less likely to occur in older adults suffering severe disabilities. Additionally, most participants were non-Hispanic white, which calls for future research on a more diverse sample. Studies have documented racial differences in functional limitations and cortisol patterns (Hajat et al., 2010). Furthermore, we acknowledge that participants' daily functional limitations may have interfered with both of their daily cortisol patterns and volunteer work. For example, older adults who temporarily experience lower limitations may show less dysregulated cortisol patterns that day and also be more likely to make it to their volunteer settings. Yet, we cannot rule out such possibilities with the current study design, nor are we able to discuss the findings in causal terms.

The type of volunteering matters but this information is missing in our data. Certain types of volunteering may be more feasible for older adults with functional limitations, which should be taken into account in future interventions targeting these older adults. The Experience Corps program has been successful in offering older adults opportunities to help elementary school students (Barron et al., 2009; Fried et al., 2004). Some opportunities like tutoring may also be customized to include older adults with functional limitations. Practitioners may encourage older adults to utilize expertise to compensate for limitations, which can benefit these older adults' mental health (Carpentieri et al., 2017). We emphasize the necessity of tracking mental health in older adults with functional limitations, in addition to their physical suffering that seems more obvious.

In summary, we present the first study that revealed the physiological benefits of volunteering to older adults with functional limitations. Findings add to the burgeoning literature that identifies these older adults as potential providers of support despite their limitations. Practically, this study offers implications for health-promotion interventions and suggests customizing volunteering opportunities for older adults with functional limitations. Practitioners should also pay attention to protecting these older adults' mental health.

Supplementary Material

Supplementary data are available at *The Journals of Gerontology, Series B: Psychological Sciences and Social Sciences* online.

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Conflict of Interest

The authors certify that they have NO affiliations with or involvement in any organization or entity with any financial interest or nonfinancial interest in the subject matter or materials discussed in this manuscript.

Author Contributions

M. Huo designed the study, wrote, and revised the manuscript. S. H. Han helped to plan the study, performed statistical analyses, and revised the manuscript. K. Kim helped to plan the study and revised the manuscript. J. Choi revised the manuscript.

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