ACCEPTED MANUSCRIPT

Lower activity linkage between caregivers and persons with neurodegenerative diseases is associated with greater caregiver anxiety

Kuan-Hua Chen, Ph.D.*[1], James J. Casey, Ph.D.*[1], Dyan E. Connelly, Ph.D.[1],
Jennifer Merrilees, Ph.D.[2], Chien-Ming Yang, Ph.D.[3], Bruce L. Miller, M.D.[2],
& Robert W. Levenson, Ph.D.[1]

*equal contribution

[1]University of California, Berkeley, Berkeley, CA, USA
[2]University of California, San Francisco, San Francisco, CA, USA
[3]National Chengchi University, Taipei, Taiwan

Short title: In-home activity linkage and caregiver anxiety

Corresponding author:
Robert W. Levenson
2121 Berkeley Way, Room 3302
University of California, Berkeley
Berkeley, CA 94720-1650
E-mail: boblev@berkeley.edu
Phone: 510-642-5050

ABSTRACT

Physiological linkage refers to the degree to which two individuals' central/peripheral physiological activities change in coordinated ways. Previous research has focused primarily on linkage in the autonomic nervous system in laboratory settings, particularly examining how linkage is associated with social behavior and relationship quality. In this study, we examined how linkage in couples' daily somatic activity (e.g., synchronized movement measured from wrist sensors)—another important aspect of peripheral physiology—was associated with relationship quality and mental health. We focused on persons with neurodegenerative diseases (PWNDs) and their spousal caregivers, whose linkage might have direct implications for the PWND-caregiver relationship and caregiver's health. Twenty-two PWNDs and their caregivers wore wristwatch actigraphy devices that provided continuous measurement of activity over seven days at home. PWND-caregiver activity linkage was quantified by the degree to which activity was "in-phase" or "anti-phase" linked (i.e., coordinated changes in the same or opposite direction) during waking hours, computed by correlating minute-by-minute activity levels averaged using a 10-minute rolling window. Caregivers completed well-validated surveys that assessed their mental health (including anxiety and depression) and relationship quality with the PWND. We found that lower in-phase activity linkage, but not anti-phase linkage, was associated with higher caregiver anxiety. These dyad-level effects were robust, remaining significant after adjusting for somatic activity at the individual level. No effects were found for caregiver depression or relationship quality. These findings suggest activity linkage and wearables may be useful for day-by-day monitoring of vulnerable populations such as family caregivers. We offered several possible explanations for our findings.

1 INTRODUCTION

Physiological linkage refers to the degree to which two individuals' central/peripheral physiological activities change in coordinated ways. Past research has predominantly studied physiological linkage in measures of autonomic nervous system (ANS) functioning during couples' interactions in the laboratory, and examined associations of linkage with social behavior and relationship quality (e.g., associations with empathic behaviors or marital satisfaction; for reviews, see: Butler, 2015; Palumbo, et al., 2016). However, most social interactions between couples occur in their homes. In addition, linkage may occur in neural systems beyond the ANS, and may have broader implications for an individual's health and well-being. In this study, we examined how linkage in couples' somatic activity (e.g., synchronized movement measured from wrist sensors) during their daily interactions in their homes was associated with self-reported relationship quality and mental health. We focused on people with neurodegenerative diseases (PWNDs) and their spousal caregivers—couples whose physiological linkage might reflect behavioral or functional changes associated with the PWND's disease. We were interested in exploring the potential implications of physiological linkage on the caregiver's health and relationship quality with the PWND.

1.1 ANS linkage

Research on ANS linkage has a long history, often examining the association between degree of linkage and quality of social interactions and relationship outcomes (for a review, see Palumbo et al., 2017). However, results from these studies have been mixed. Some studies found greater ANS linkage was associated with higher-quality interactions or relationships (Helm et al., 2014; Marci et al., 2007; Marci & Orr, 2006) while others observed the opposite (i.e., greater physiological linkage was associated with worse relationship/interaction quality; Gates et al.,

2015; Liu et al., 2013; Saxbe & Repetti, 2010). Among the many factors that may have contributed to these disparate findings, one possibility is the way that ANS linkage was computed. For example, interactants' ANS can be linked either *in-phase* (e.g., their heart rates rise and fall at the same time) or *anti-phase* (e.g., one person's heart rate rises while at the same time the other person's heart rate falls; Reed, Randall, Post, & Butler, 2013). In most previous research, these two types of linkage have not been examined separately but rather both have been included in measures of *total linkage*. In a recent study, we examined in-phase and anti-phase linkage separately during face-to-face interactions between married couples. We found that in-phase linkage was greater during moments when the couples shared positive emotions compared to other moments of the conversation. In addition, greater in-phase linkage during these moments was associated with higher relationship satisfaction. In contrast, anti-phase linkage was marginally greater during moments when the couples shared negative emotions. Higher anti-phase linkage during these moments was associated with worse relationship satisfaction (Chen, et al., 2020).

1.2 Somatic activity linkage

Human peripheral physiology includes both the ANS and the somatic nervous system. While both systems are highly interactive and often activated together, previous research on physiological linkage has focused predominately on the ANS (Palumbo, et al., 2016). Somatic activity creates metabolic demands that result in ANS changes, particularly in the cardiac and vascular systems (Levenson, 2014; Obrist, Webb, Sutterer, & Howard, 1970). Although research on somatic activity linkage has been rare (and no studies to date have compared the effects of in-phase versus anti-phase somatic activity linkage), existing evidence suggests a positive association between greater total linkage in somatic activity and positive outcomes of the social

interaction and relationship. For example, Julien and colleagues (2000) found that highly satisfied romantic couples showed more synchronicity of immediacy behaviors (i.e., behaviors that express connectedness) during conversations than did dissatisfied romantic couples. More recently, Chang and colleagues (2017) found that greater linkage in joint activity between musicians in real-time performance was associated with higher levels of self-rated performance quality. Similarly, experimentally-induced synchronous activity between participants has been found to produce greater compassion and altruism (Valdesolo & DeSteno, 2011). Although there are many ways to measure activity linkage, one promising and well-validated method is through actigraphy obtained through sensors worn on the wrist or other part of the body that measure body or limb movements (Bussmann, Tulen, van Herel, & Stam, 1998; Patterson, et al., 1993). Wearable actigraphy has the advantages of not requiring complicated site preparation and application of electrodes, not requiring tethering of participants to recording equipment, and enabling recordings to be made over long time periods in the person's home (Pauly, et al., 2019; Poole, et al., 2011). Wearable actigraphy is also less vulnerable to some of the artifacts that affect other sensors (e.g., wearable optical heart rate sensors; Bent, Goldstein, Kibbe, & Dunn, 2020).

1.3 Studying linkage in the laboratory versus in naturalistic settings

Most research on physiological linkage between couples has been conducted in laboratory settings, using a dyadic interaction procedure that was initially developed by Levenson and Gottman (1983). In this procedure, couples sit quietly for 5 minutes and then have a 15 minute face-to-face discussion of a problem area in their relationship and attempt to reach some solution or compromise. Throughout the procedure, physiological responses are recorded continuously. Although studies conducted in laboratory settings provide advantages in

maximizing experimental control, they only provide a snapshot of couples' linkage in a relatively brief, highly structured context (e.g., a 15-minute conflict conversation). These studies do not assess linkage that occurs over longer time periods and that span more diverse kinds of social interaction (e.g., shared leisure activities). A few studies have applied a more ecologically-valid approach and examined physiological linkage over multiple days in couples' homes, but these studies have predominately focused on hormonal responding (e.g., cortisol) or sleep patterns that fluctuate relatively slowly (e.g., over hours or days; Liu, Rovine, Cousino Klein, & Almeida, 2013; Pauly, et al., 2020; Saxbe & Repetti, 2010). Studies of physiological linkage conducted in home settings using physiological measures sensitive to rapid changes (e.g., somatic activity) have been rare but could present a unique opportunity to study linkage in more representative real-world contexts.

1.4 Activity linkage, relationship quality, and health

Measuring couples' somatic activity linkage in their homes may provide a novel window into naturalistic daily social interactions, which may reveal important associations with relationship quality and health. For example, greater in-phase linkage in somatic activity may reflect higher concordance in daily routines and health behaviors (e.g., sleeping and eating at the same time; doing exercise, housework, or leisure activities together). It may also reflect similar experiences of the same internal or external stimulus. For example, couples might recall a shared memory of joy leading to their laughing at the same time (both of which often occur in positive relationships and may lead to better health outcomes; Kiecolt-Glaser & Wilson, 2017). In contrast, greater anti-phase linkage in somatic activity may reflect quite different daily interaction patterns such as when one person is sitting in front of a TV while the other person is

preparing a meal, or when one person is sharing distressing events and the other person is not responsive, offering neither empathy nor support.

1.5 Activity linkage in neurodegenerative disease and family caregiving

Neurodegenerative diseases and associated family caregiving provide a powerful model for studying the associations among naturalistic activity linkage, relationship quality, and health outcomes. PWNDs, such as those with dementia, experience progressive declines in cognitive, socioemotional, and motor functioning. These declines profoundly change PWNDs' daily activities, including dyadic interactions with their spouses, who often serve as their primary caregiver. A multitude of studies have demonstrated heightened risk for adverse relationship and mental health outcomes in these caregivers (e.g., greater anxiety and depression) as a result of increased strain and burden associated with caregiving, as well as the appearance of disruptive behavioral symptoms in the PWND including apathy, disinhibition, etc. (Cuijpers, 2005; Kolanowski, Fick, Waller, & Shea, 2004; Schulz, O'Brien, Bookwala, & Fleissner, 1995). However, there are also striking individual differences among caregivers in how profoundly they experience these adverse effects (Hua, Wells, Brown, & Levenson, in press; Wells, et al., 2019). Together, the heterogeneity of disease-related and caregiving-related changes in PWNDs and caregivers, respectively, provides an opportunity to examine how daily activity linkage is associated with couples' relationship quality and health in what is becoming an increasingly common late-life relationship (e.g., recent estimates suggest that there are 1.1 million spousal caregivers for PWNDs in the U.S. alone; Alzheimer's Association, 2021)

1.6 The current study

The current study examines the associations between PWND-caregiver activity linkage measured in a naturalistic home setting, relationship quality, and caregiver health. To quantify

activity linkage, PWNDs and their primary caregivers wore actigraphy devices on their wrists for seven consecutive days in their home and their activity linkage was computed during waking hours. Caregivers' relationship quality was assessed using a well-established self-report questionnaire (Locke & Wallace, 1959). In terms of caregiver health, we focused on mental health, measured using well-validated self-report measures of anxiety and depression (Radloff, 1977; Steer & Beck, 1997; see the Methods section for details). Based on the literature reviewed above, we hypothesized that lower in-phase and higher anti-phase activity linkage would be associated with lower relationship quality, greater caregiver anxiety, and greater caregiver depression.

2 METHODS

2.1 Participants

Twenty-two PWNDs and their spousal caregivers were recruited through the Memory and Aging Center at the University of California, San Francisco (UCSF). The average age for PWNDs was 61.7 ($SD = 14.2$) and for caregivers was 65.4 ($SD = 8.9$). Among PWNDs, 15 were female and seven were male; among caregivers, seven were female and 15 were male. All dyads were either in married ($n = 21$ dyads) or unmarried committed ($n = 1$ dyad) relationships; all dyads lived together. Among married dyads, average marriage length was 30.7 years ($SD = 16.7$). PWND diagnoses were determined by a team of neurologists, neuropsychologists, and nurses at UCSF using structural MRI, neuropsychological testing, and clinical interviews. Among PWNDs, five met diagnostic criteria for behavioral-variant frontotemporal dementia (bvFTD; Rascovsky, et al., 2011), four for semantic variant primary progressive aphasia (svPPA), two for nonfluent variant primary progressive aphasia (nfvPPA; Gorno-Tempini, et al.,

2011), six for Alzheimer's disease (AD; McKhann, et al., 2011), two for progressive supranuclear palsy (PSP; Litvan, et al., 1996), one for corticobasal syndrome (CBS; Armstrong, et al., 2013), one for Parkinson's disease (PD) , and one for mild cognitive impairment (MCI; Petersen, 2004). PWND and caregiver demographics are presented in Table 1.

2.2 Procedure

PWNDs participated in three days of testing at UCSF, followed by a one-day laboratory assessment of emotional functioning (Levenson, 2007) at the Berkeley Psychophysiology Laboratory at the University of California, Berkeley (UCB). The UCB session was scheduled as soon after the UCSF assessment as possible (generally within two weeks). Informed consent was obtained upon arrival at both sites. All procedures were approved by the UCSF and UCB Institutional Review Boards.

Prior to the UCB assessment, participants completed a questionnaire packet that included demographic and health measures. During the day of the UCB assessment, PWNDs and caregivers were each given an actigraphy wristwatch (described below) and daily sleep diary that were to be used over the subsequent seven days. Participants were provided with a stamped envelope to return the watches and diaries after the in-home assessment was completed.

2.3 Apparatus and measures

2.3.1 Actigraphy

The Philips Respironics Actiwatch 2 actigraph along with Actiware software version 6.0.5 was used to measure activity. The wrist-worn actigraph contained an accelerometer to measure how much the wearer moves, and a light sensor to measure the level of ambient light. The actigraph sampled accelerometer data at 32 Hz. The validity and reliability of actigraphs for

measuring activity in older adults have been established in previous research (Evenson, Buchner, & Morland, 2012). PWNDs and caregivers each wore the actigraph on the wrist of their non-dominant hand continuously over the seven days of in-home assessment except when bathing or swimming. The battery of the actigraph was fully charged prior to giving it to participants and did not need to be recharged during the 7-day study period.

2.3.2 Sleep diary

Participants completed a daily sleep diary each evening before going to bed and each morning upon awakening for seven days. The diaries recorded the time of day they went to bed, the time they woke up, the number and time of any naps, and any times they did not wear the actigraphs. Sleep diary data were used to determine periods when participants were asleep or awake (the determination was supplemented with information collected by the actigraphy wristwatch; see Data Reduction section below). If needed, caregivers helped PWNDs complete the diaries.

2.3.3 PWND dementia severity

To ensure that the effects of any association between activity linkage and caregiver mental health did not simply reflect the severity of PWNDs' dementia symptoms, we included the Clinical Dementia Rating (CDR; Morris, 1993) as a potential covariate. The CDR was administered at UCSF for each PWND. It consists of a structured interview with the caregiver regarding the PWND's impairment in six domains of functioning (memory, orientation, judgment and problem solving, community affairs, home and hobbies, and personal care). The CDR yields two scores: (a) Total score (CDR-Total), which ranges from 0 to 3 (0 = normal, 0.5 = very mild dementia; 1 = mild dementia, 2 = moderate dementia, 3 = severe dementia); (b) Sum

of boxes score (CDR-Box), which ranges from 0 to 18, with higher values indicating greater severity. In data analyses, we used CDR-Box because it is continuous and has a greater range, making it more sensitive to dementia severity. The CDR has been validated against neuropathology data (Berg, McKeel, Miller, Baty, & Morris, 1993) and demonstrates good reliability (Burke, et al., 1988).

2.3.4 PWND-Caregiver relationship quality

Caregivers self-reported their relationship quality with the PWNDs on the Martial Adjustment Test (Locke & Wallace, 1959), a measure we have used extensively in our previous research with couples (Chen, et al., 2020; Levenson & Gottman, 1983). The test consisted of 15 items (e.g., "Do you confide in your mate?"). The total score of all items was computed, with a higher value indicating better relationship quality. Reliability for the test is high (e.g., split-half reliability = .90; Locke & Wallace, 1959).

2.3.5 Caregiver employment status and weekly working hours

As part of the questionnaire packet, caregivers reported their current employment status and the number of hours they worked each week. These measures served as potential covariates because of their possible relationship with caregiver anxiety and depression as well as the time each caregiver spent interacting with the PWND in their home. For caregiver current employment status we created dummy variables for each of five categories (working full time, working part time, unemployed, retired, other) such that we coded "1" when the endorsed response fell into the category and "0" when it did not (a caregiver who was working full time would be coded "1" for "working full time" and 0 for all the other variables). Note that

caregivers were only allowed to endorse one category that best describes they current employment status.

2.3.6 Caregiver burden

We included caregiver burden as a potential covariate because previous research had reported a robust association with caregivers' mental health (for a review, see Schulz, Beach, Czaja, Martire, & Monin, 2020). Caregivers completed the short version of the Zarit Burden Interview (ZBI-S; Bédard, et al., 2001), a 12-item self-report instrument that has been widely used in research on dementia caregivers. ZBI scores ranged from 0 to 48, with higher scores indicating greater burden. ZBI-S' validity (correlations to the original full Zarit Burden Scale; Zarit, Orr, & Zarit, 1985) and reliability have been demonstrated in previous studies (Bédard, et al., 2001; O'Rourke & Tuokko, 2003).

2.3.7 Caregiver anxiety

Caregivers completed the Beck Anxiety Inventory (BAI; Beck, Epstein, Brown, & Steer, 1988), a well-validated 21-item self-report scale of how bothered they were by different anxiety symptoms in the previous month (e.g., "nervous"; 0 = "Not at all," 3 = "Severely – it bothered me a lot"). Scores ranged from 0 to 63, with higher scores indicating greater anxiety. This measure has shown reasonable levels of reliability and validity with individuals with anxiety disorders in previous studies (Beck, Epstein, Brown, & Steer, 1988; Fydrich, Dowdall, & Chambless, 1992).

2.3.8 Caregiver depression

Caregivers completed the Center for Epidemiological Studies Depression scale (CES-D; Radloff, 1977), a well-validated 20-item self-report scale of how frequently they experienced

depression symptoms in the previous week (e.g., "I felt sad"; 0 = "Rarely [Less than 1 day]," 3 = "Most or all of the time [5-7 days]"). Scores ranged from 0 to 60, with higher scores indicating greater depression. The CES-D has been previously validated for measuring depression in older adults (Beekman, et al., 1997; Haringsma, Engels, Beekman, & Spinhoven, 2004).

2.4 Data Reduction

2.4.1 Awake time periods

The time periods when each PWND and caregiver were awake were determined based on (a) diary reports of when they were awake and (b) actigraphy measures of more than 40 movements that were above a default threshold of acceleration within a given minute-long period (Obayashi, Saeki, & Kurumatani, 2014).

2.4.2 Individual activity levels

Separately for each PWND and caregiver, levels of activity were determined from the minute-by-minute actigraphy data (e.g., Figure 1A). Minutes with missing data (e.g., when a participant took off the actigraph to shower) were identified using the sleep diary and visual inspection of the activity data. Daily activity levels for each participant were computed as the average of all available minutes for each of the seven days during times when both the PWND and caregiver were awake and wearing their actigraphs. Daily activity data were excluded for any day in which the minute-by-minute linkage scores could not be computed for over 20% of the couple's common awake hours (see below for details). Scores for seven-day activity levels were computed by averaging the daily activity values for all available days for the PWND and the caregiver.

2.4.3 Dyadic in-phase and anti-phase activity linkage.

For each PWND-caregiver dyad, minute-by-minute activity linkage was computed using their activity data. Using a "rolling window" approach (Chen, et al., 2020; Gates, Gatzke-Kopp, Sandsten, & Blandon, 2015; Marci, Ham, Moran, & Orr, 2007), we computed Pearson correlations between the PWND's and caregiver's activity during successive 10-minute windows (advanced one minute at a time) when the PWND and the caregiver were both awake. We selected 10 minutes as our time window because it is long enough to provide sufficient variation to compute correlations but not too long to obscure any short-lasting changes in linkage.

Because Pearson correlations require a minimum of two variables with at least seven data points to be reliable (Aggarwal & Ranganathan, 2016), we considered a 10-minute window to be "missing" if the dyadic PWND and caregiver activity data were available for less than seven minutes. Using this approach, there were 474 missing windows across all participants, which represented 2.67% of all data collected. Pearson correlations also require both variables to have some variability, that is, to not be constant. When people are engaged in activities that do not involve a lot of movement (e.g., meditation, watching television), they may show no actigraphy for fairly long time periods. In our analyses, if both the PWND's and caregiver's actigraphy remained constantly at zero (thus Pearson correlations could not be computed; see Table 1 for its descriptive statistics), we coded the linkage score for this 10-second time period as "1"; if one person's actigraphy remained zero and the other's did not (Pearson correlations could not be computed, neither), we coded the linkage score as "0".

Using the rolling window approach, we computed a total linkage score for each PWND-caregiver dyad centered on each waking minute during the seven-day assessment period. Because the total linkage scores were based on correlations, they ranged from +1 to -1 (Figure

1B). Based on the time series of total linkage[1], we further computed a time series of *in-phase linkage* and a time series of *anti-phase linkage* using a similar approach as that in our previous research (Chen, et al., 2020). For each minute of the in-phase linkage time series, we either entered the correlation coefficient from the relevant total linkage time series if it was positive, or entered a 0 if the correlation was 0 or negative (Figure 1C). Similarly, for each minute of the anti-phase linkage time series, we either entered the relevant total linkage correlation coefficient if it was negative, or entered 0 if it was 0 or positive. (Figure 1D). Prior to statistical analyses, correlations in the anti-phase linkage time series were multiplied by -1 so that higher positive values in both in-phase and anti-phase linkage time series reflected greater linkage.

In-phase and anti-phase linkage scores were first averaged for each of the seven days. Daily average linkage scores were excluded for any day when the minute-by-minute linkage scores could not be computed for over 20% of the time when both members of the dyad were awake (e.g., if one or both did not wear the actigraph). On average 22.72% or 1.59 days of the data were excluded (note that most dyads started and ended data recording in the middle of the first and last day, respectively, thus, these days were not included in the analyses; when not counting the first and last days, 12.72 % or 0.64 days of the data were excluded; see Table 1 for the descriptive statistics of total days and hours per day included in the data analyses). We then averaged the scores across all available days to calculate the overall activity linkage score for each dyad. Due to our modest sample size, we did not exclude any dyads due to the number of day of data unavailable.

---

[1] To ensure that our results were robust, we also analyzed the total linkage scores before separating them into in-phase and anti-phase scores. Similar results were found, i.e., lower PWND-caregiver activity total linkage was marginally associated with higher caregiver anxiety ($r = -.37$, $p = .08$).

3 RESULTS

3.1 Preliminary analyses

We used Pearson correlations to identify possible demographic covariates for primary data analyses. As shown in Table 2, neither in-phase nor anti-phase activity linkage was significantly associated with: (a) PWNDs or caregivers' age, gender, activity level, or maximum length of inactivity (i.e., the actigraphy level remained constantly at zero) during waking hours; (b) PWNDs' dementia severity, (c) caregivers' employment status, weekly working hours, and burden, as well as (d) dyadic factors including the length of marriage, total days or hours per day included in data analyses, and the total number of 10-minute time windows during which both PWNDs and caregivers were inactive. Thus, none of these variables were included as covariates in the primary analyses.

A Pearson correlation was also computed between anxiety and depression scores for caregivers. The analysis revealed a significant correlation ($r = .63$, $p = .002$). We did not consider this correlation to be sufficiently high to justify creating an aggregate "mental health" score and thus analyzed anxiety and depression separately.

3.2 Primary analyses

3.2.1 Activity linkage and relationship quality

We conducted two Pearson's correlations to test the associations between PWND-caregiver activity linkage (separately for the in-phase and anti-phase linkage) and PWND-caregiver relationship quality. Results revealed no significant effects (in-phase: $r = 0.13$, $p = .59$; anti-phase: $r = -.05$, $p = .82$).

3.2.2 Activity linkage and caregiver anxiety

To test our hypothesis that lower PWND-caregiver activity linkage would be associated with higher caregiver anxiety, we conducted two Pearson's correlations for activity linkage (separately for the in-phase and anti-phase linkage) and caregiver anxiety. Results revealed a significant negative association between in-phase activity linkage and caregiver anxiety ($r = -.45$, $p = .03$; Figure 2A), such that lower in-phase activity linkage was associated with higher caregiver anxiety. Interestingly, there was a positive association between anti-phase activity linkage and caregiver anxiety; however, the effects did not approach statistical significance ($r = .24$, $p = .28$; Figure 2B).

We took the following precautions to ensure that our handling of missing data and mutual inactivity was appropriate and that our findings were robust—specifically, we coded linkage scores for time windows with less than seven datapoints as "missing"; for time windows in which both PWNDs and caregivers were constantly inactive as "1". We first repeated our primary analysis by including all time windows regardless of the number of data points. We then repeated our primary analysis again by excluding time windows in which both partners remained inactive. Both analyses revealed very similar associations between in-phase activity linkage and caregiver anxiety (for the first analysis: $r = -.46$, $p = .03$; for the second analysis: $r = -.40$, $p = .06$). To ensure our findings based on analyzing the 10-minute windows were robust to other time periods, we repeated our primary analysis using 7-minute and 15-minute time windows. Very similar results were found, i.e., lower in-phase activity linkage was associated with higher caregiver anxiety (7 minute: $r = -.43$, $p = .049$; 15 minutes: $r = -.47$, $p = .028$). To ensure that the results using the overall linkage approach (i.e., averaging daily linkage scores across available days) were robust, we repeated our primary analysis using the daily in-phase linkage score from

the day in which the in-phase linkage was greatest among the study period. Again, a very similar association between in-phase linkage and caregiver anxiety was found ($r = -.43$, $p = .046$).

Although all caregivers were asked to complete the self-report questionnaires before the UCB assessment, two caregivers completed them shortly after their UCB assessment (i.e., 1 and 32 days later); another two caregivers completed them with a longer delay (i.e., 155 and 236 days). To ensure our findings were robust to these differences, we repeated our primary analysis by excluding the two caregivers who returned the questionnaire packet with a long delay. Results still revealed a significant negative association between in-phase activity linkage and caregiver anxiety ($r = -.45$, $p = .048$). In addition, although all participants were asked to wear the watch for seven consecutive days, three dyads only provided valid data for four days or fewer. To ensure our reported results were robust to these differences, we repeated our primary analysis by excluding these three dyads. Results still revealed a significant negative association between in-phase activity linkage and caregiver anxiety ($r = -.55$, $p = .016$).

3.2.3 Activity linkage and caregiver depression

To test our hypothesis that lower PWND-caregiver activity linkage would be associated with higher caregiver depression, we conducted two Pearson's correlations for activity linkage (separately for in-phase and anti-phase linkage) and caregiver depression. Results revealed no significant effects (in-phase: $r = -.24$, $p = .28$; anti-phase: $r = .20$, $p = .38$).

Because our analyses only revealed significant effects for the association between PWND-caregiver in-phase activity linkage and caregiver anxiety, we focused on this association in the specificity analyses reported below.

3.2.4 Specificity of effect

Activity linkage was computed based on the activity of both PWNDs and caregivers. To ensure that our findings were specific to the dyadic measure of "linkage," rather than simply driven by changes in caregivers or PWNDs' individual activity levels, we conducted a multiple regression analysis in which PWND activity level, caregiver activity level, and PWND-caregiver in-phase activity linkage were entered as independent variables, and caregiver anxiety was the dependent variable[2]. We found that PWND-caregiver in-phase activity linkage remained significantly associated with caregiver anxiety in this analysis (β = -.43, p = .04), whereas the other independent variables were not (PWND activity: β = -.34, p = .10; caregiver activity: β = .003, p = .987). The results of this analysis are shown in Table 3.

3.2.4 Unique value of assessing PWND-caregiver linkage

Previous research has revealed a robust association between greater caregiving burden and worse caregiver mental health (for a review, see Schulz, Beach, Czaja, Martire, & Monin, 2020). Following our main research findings reported above, we conducted exploratory analyses to determine whether the assessment of PWND-caregiver activity linkage added additional value to caregiver burden in explaining caregiver anxiety. We performed a stepwise multiple regression in which caregiver burden and PWND-caregiver in-phase linkage were separately entered as independent variables in steps 1 and 2 and caregiver anxiety was the dependent variable. This analysis revealed that while greater caregiver burden alone was significantly

---

[2] To compare, we repeated the specificity analysis using caregiver depression as the dependent variable. Results from this analysis confirmed that there was no significant association between caregiver depression and in-phase activity linkage (β = -.21, p = .32), PWND activity (β = -.42, p = .06), or caregiver activity (β = -.04, p = .85).

associated with greater caregiver anxiety (β = .53, p = .014), adding PWND-caregiver activity

linkage as an additional independent variable significantly improved the model by accounting for

more variances in caregiver anxiety (ΔR^2 = .21, p = .014). Importantly, in the second model, both

greater caregiver burden (β = .45, p = .017) and lower PWND-caregiver activity linkage (β = -

.46, p = .014) were significantly associated with greater caregiver anxiety. These results are

shown in Table 4.

4 DISCUSSION

We measured real-world PWND-caregiver activity linkage using actigraphy devices

worn in the home and examined associations between activity linkage and caregiver mental

health and PWND-caregiver relationship quality. Our main findings indicate that lower PWND-

caregiver in-phase activity linkage (but not anti-phase linkage) was associated with greater

caregiver anxiety. These effects remained statistically significant when adjusting for PWNDs'

and caregivers' overall activity levels, indicating that these results are specific to the dyadic

level. We also found that PWND-caregiver in-phase activity linkage accounted for additional

variances in caregiver anxiety beyond caregiver burden. PWDN-caregiver activity linkage was

not associated with either caregiver depression or PWND-caregiver relationship quality.

4.1 Activity linkage and caregiver anxiety

Actigraphy devices provide a continuous measure of somatic activity, which is an

important aspect of human peripheral physiology that is often co-activated with the ANS in

response to everyday challenges and opportunities (Levenson, 2014). Our finding that lower

PWND-caregiver in-phase activity linkage was associated with greater caregiver anxiety is

consistent with previous findings that lower linkage in other physiological measures (e.g., heart rate) was associated with worse social and psychological outcomes. For example, weaker linkage of respiratory sinus arrhythmia (a measure of parasympathetic nervous system influence on the heart) in couples, and less-synchronized immediacy behaviors (nonverbal behaviors that express soothing and connectedness), are both associated with lower relationship satisfaction in couples (Helm, Sbarra, & Ferrer, 2014; Julien, Brault, Chartrand, & Bégin, 2000). Similarly, in our own work (Chen, et al., 2020), we have found that weaker in-phase linkage in couple's ANS responses during moments of shared positive emotions in a laboratory conflict conversation was associated with lower perceived quality of both the interaction and the relationship (i.e., six years later). Findings from the current study extend those from this previous work by providing the first demonstration of an association between lower physiological linkage in couples' daily real-world lives and worse mental health outcomes.

We believe these findings result from lower in-phase activity linkage serving as an indicator of fewer concordant daily routines and shared activities and behaviors between PWNDs and caregivers. Frontotemporal dementia, Alzheimer's disease, and Parkinson's disease are neurodegenerative diseases that are associated with progressive impairment in the PWNDs' cognitive, motor, and daily functioning (Emre, 2003; G. McKhann et al., 1984; Rascovsky et al., 2011). Behavioral changes such as increased apathy and agitation are also increasingly common over time (for a review, see Teng, Marshall, & Cummings, 2011). These changes in PWNDs may reduce the PWNDs' ability to engage in joint activities (e.g., exercise or play cards together) and maintain meaningful interactions with their caregivers. These reductions in interactive behaviors would be reflected in decreased PWND-caregiver activity linkage. Given this lowered level of coordinated interaction, caregivers may experience greater anxiety about PWNDs'

increasing symptoms, functional declines, and likelihood of become more socially disconnected in the future.

Another potential explanation for the associations between lower in-phase activity linkage and greater caregiver anxiety is based on emotion regulation via social connections. A long history of research has demonstrated that being connected to and supported by social partners is crucial to buffer stress and burden and regulate negative emotions in both caregiving and non-caregiving contexts (Dias, et al., 2015; Seppala, Rossomando, & Doty, 2013). For example, when anticipating an electric shock, holding the hand of a loved one was shown to reduce the brain's threat response, especially in those who mutually cared about each other (Coan, Kasle, Jackson, Schaefer, & Davidson, 2013). In our own work, we have found caregivers have better mental health when they remained socially connected with the PWNDs , and when the PWNDs under their care are more empathically accurate and display more frequent "genuine" smiles (a type of smile that is associated with greater social connectedness; Hess & Bourgeois, 2010) during laboratory interactions (Connelly, Verstaen, Brown, Lwi, & Levenson, 2020; Lwi, et al., 2018). In the current study, caregivers with greater in-phase activity linkage with the PWND in their care may be experiencing more instances of shared calming behaviors such as hand holding and hugging. Highly in-phase linked caregivers and PWNDs may also often have shared thoughts and emotions, similar reactions to the same stimuli (e.g., laughing together at a humorous event), and greater attentiveness and responsiveness to each other (e.g., being empathic and sympathetic when the other person shares a sad story) during their everyday interactions. All of these could serve emotion regulatory functions in increasing comfort and reducing anxiety.

Our findings may also reflect the amount of time PWNDs and caregivers spend occupying the same space and being visible to each other during waking hours. Previous studies have found that caregivers often report worrying that the PWNDs will wander off or accidentally harm themselves and often endorse supervising the PWNDs as an important way to prevent these things from happening (Lach & Chang, 2007). If PWNDs and caregivers are occupying the same space, this may allow for more frequent interactions and easier supervision, and, thus, lower caregiver anxiety. Additionally, being physically present and interacting together invites behavioral mimicry (Chartrand & Lakin, 2013), which would register as activity linkage in the current study. Conversely, if caregivers and PWNDs are largely separated, activity linkage and behavioral mimicry would presumably be lower and caregivers could experience greater anxiety as they worry about harm that might befall the unsupervised PWND. Given these possibilities, future research would benefit from collecting data about PWNDs' and caregivers' physical proximity (Arguello, et al., 2018) and/or location in the home (e.g., whether they are in the same or different rooms; Kernebeck, et al., 2019) to better understand the conditions under which activity linkage occurs..

4.2 Activity linkage and caregiver depression

We had hypothesized that lower in-phase activity linkage and higher anti-phase activity linkage would also be associated with greater caregiver depression. These associations were in the predicted direction but did not reach statistical significance. As is often the case with research with PWNDs, our sample size was modest, which limited our power to detect small-sized effects. Although it is certainly possible that activity linkage reflects aspects of the PWND-caregiver relationship that are more closely connected with anxiety than depression, definitive determination of this kind of differential effect awaits future studies with larger samples.

4.3 Activity linkage and relationship quality

Based on previous research we had hypothesized an association between activity linkage and relationship quality. This association was not supported by our results. Although our sample size was modest, thus limiting confidence in nonsignificant effects, our findings are consistent with other in-home activity linkage research where activity linkage was not found to be associated with couples' relationship quality (Pauly, et al., 2019). Given that the associations between activity linkage and relationship quality have also been reported in laboratory studies (Julien et al., 2000), we speculate variability in the valence, intensity, contents, and duration of couples in-home interactions may have diluted the effects observed in laboratory research using briefer and more structured interactions (e.g., 15-minute conversations about relationship problems, which can create highly charged emotional exchanges; Levenson & Gottman, 1983).

Different findings between laboratory and real-world studies may also reflect temporal differences in data reduction. For example, in our previous work, activity data obtained in the laboratory were reduced to one or 10 second averages for quantifying physiological linkage (Chen, et al., 2020; Levenson & Gottman, 1983). In contrast, in the current and a previous (Pauly, et al., 2019) real-world studies, actigraphy data were reduced into 1 or 60 minute averages for linkage analyses. Because human somatic physiology often changes rapidly (Levenson, 2014; Tassinary, Cacioppo, & Vanman, 2007), longer averaging periods may have limited the ability of these real-world studies to detect more short-term patterns of activity linkage that have unique associations with couples' relationship quality.

4.4 PWND daily activity and caregiver anxiety

Interestingly, our study did not find a significant association between PWNDs' daily activity levels and caregiver anxiety. Disease-related cognitive, behavioral, and/or functional changes in PWNDs may result in changes in their daily activities. These changes could be signs of disease worsening, and are likely to increase caregivers' worry. At first glance, our results seem counterintuitive. However, we note that PWNDs' changes in cognition, behaviors, and functions can manifest in either increased or decreased levels of activity. For example, increased daily activities (measured through actigraphy) were found in PWNDs with greater agitation and aberrant motor behaviors whereas decreased daily activities were found in those with apathy or motor dysfunctions (James, Boyle, Bennett, & Buchman, 2012; Knuff, Leung, Seitz, Pallaveshi, & Burhan, 2019; Valembois, et al., 2015). PWNDs' levels of daily activities may be further complicated by individual factors such as PWND age, gender, lifestyle, the physical size of household, etc., making it more challenging to find clear associations between PWNDs' daily activity levels as measured by actigraphy and caregivers' anxiety.

4.5 Activity linkage, caregiver anxiety, and burden

The association between caregiving burden and declining mental health in family caregivers has been well-recognized in the literature (for a review, see Schulz, Beach, Czaja, Martire, & Monin, 2020). Extending this previous work, our findings suggest that changes in dyadic interpersonal processes—manifested as lower activity linkage—explain additional variances in caregiver mental health symptoms. Importantly, in our study, PWND-caregiver activity linkage and caregiver burden were not significantly associated with each other, and both (i.e., lower linkage and greater burden) were separately associated with greater caregiver anxiety. These findings suggest that lower PWND-caregiver activity linkage was not simply a reflection

of burden-related daily activity changes in PWNDs (e.g., loss of autonomy) and caregivers (e.g., taking greater responsibilities).

4.5 Implications

Although the generalizability of our findings to other contexts and populations (e.g., neurotypical older couples, caregivers of a loved one with other chronic diseases) remains to be determined, our findings underscore an important association between dyadic physiology and health, which occurs above and beyond individual level effects (Poole, et al., 2011). In addition, our findings indicate that wearable actigraphy devices are a promising and innovative strategy for effectively exploring the association between physiological linkage and mental health in naturalistic settings. In the context of neurodegenerative diseases, caregivers of PWNDs experience much higher rates of mental health problems than non-caregivers at similar ages (Pinquart & Sörensen, 2003; Schulz, Beach, Czaja, Martire, & Monin, 2020). Therefore, discovering tools that are easy to deploy for everyday use and that may be capable of identifying caregivers at heightened risk of health decline may help in developing and monitoring future interventions aimed at protecting caregiver health and well-being.

4.6 Strengths and limitations

The main strengths of this study include examining activity linkage in a naturalistic setting and for a relatively long period of time (i.e., seven days). Thus, dyadic behaviors and interactions that contributed to our measure of activity linkage may have been more representative of "regular life" than in research conducted in laboratory settings over much shorter time periods. Additionally, in-phase and anti-phase activity linkage were evaluated separately in our study, which helped us to determine the precise patterns of linkage that were

associated with caregiver mental health. Moreover, we examined the unique value of activity linkage and found that it accounted for additional variances in caregiver anxiety above and beyond caregiver burden, which has a well-established relationship with caregiver anxiety. Finally, our analyses, which considered activity at both the individual and dyadic level, demonstrated that the observed effects were specific to the dyadic measures. This finding underscores the importance of including dyadic measures in studies of health in caregivers (and arguably also in other relationship partners) and adds substantially to our prior research that has studied caregiver health in relationship to measures obtained only from PWNDs (e.g., Chen, et al., 2017) or only from caregivers (Wells, et al., 2019).

The study also had several limitations. Our modest sample size limited our power to detect smaller effect sizes and our ability to interpret potential mechanisms (i.e., specific behaviors and types of interactions that lead to increased PWND-caregiver linkage). We included PWNDs with heterogeneous disease diagnoses to increase heterogeneity of PWND functioning and caregiver health (which is useful for mapping the association between physiological linkage and health), but this approach and our modest sample size limited our ability to determine whether our findings were moderated by PWND diagnosis. Measuring somatic activity via actigraphy has many advantages (e.g., objective, continuous, unobtrusive), but it cannot reveal the finer-grained details of specific behaviors (e.g., calming each other, eating dinner together). Assessing these specific behaviors could reveal the unique associations among particular behaviors and interactions, levels of activity linkage, and caregiver health. Not having a comparison group of age-matched couples without neurodegenerative disease made it impossible to determine whether the found associations between activity linkage and anxiety were unique to couples in which one person had a neurodegenerative disease. In addition, with

our correlational design, we could not determine the directional influences between lower activity linkage and greater caregiver anxiety. Thus, we cannot know whether low levels of activity linkage worsen caregivers' anxiety, greater caregiver anxiety reduces activity linkage, or both. Additionally, measures of caregiver health and relationship quality were not assessed simultaneously with activity linkage ; therefore, we cannot rule out the possibility that some caregivers might have undergone significant health and/or relationship quality changes during the time period between finishing the questionnaires and completing the in-home assessments. Finally, the current study focused on somatic activity and did not examine linkage in other aspects of peripheral physiology (e.g., ANS measures). Although these systems often activate together in response to everyday challenges and opportunities (Levenson, 2014; Obrist, Webb, Sutterer, & Howard, 1970), they also may have different patterns of activation in the context of different emotions and behaviors (Ekman, Levenson, & Friesen, 1983; Levenson, 2014). Therefore, whether our findings on activity linkage can be generalized to other real-world physiological measures (e.g., minute-by-minute heart rate) remains to be determined.

4.7 Conclusion

Physiological linkage between couples has been studied predominately in the laboratory and found to be associated both with relationship quality and the nature of dyadic interactions. The current study is the first to demonstrate that physiological linkage examined in real-world settings may be associated with the mental health of at least one of the interactants. Our findings were conducted with PWNDs and their caregivers and suggest that these methods could be used with other populations as well. We look forward to future studies investigating the generalizability of our findings to other populations as well as those that further elucidate the specific behaviors and types of interactions that lead to increased in-home linkage. Given the

technological advances and growing popularity of wearable devices (e.g., Apple Watch, Fitbit;

Kim, Campbell, de Ávila, & Wang, 2019), future research in this domain can foster developing

and validating new tools for assessing real-world social behaviors and determining the ways that

these behaviors are related to health and well-being in healthy populations as well as in

vulnerable groups such as PWNDs and their caregivers.

REFERENCES

Aggarwal, R., & Ranganathan, P. (2016). Common pitfalls in statistical analysis: The use of correlation techniques. *Perspectives in Clinical Research*, **7**, 187-190.

Alzheimer's Association (2021). 2021 Alzheimer's disease facts and figures. *Alzheimer's & Dementia* (**Vol. 17**, pp. 327-406).

Arguello, D., Andersen, K., Morton, A., Freedson, P.S., Intille, S.S., & John, D. (2018). Validity of proximity sensor-based wear-time detection using the ActiGraph GT9X. *Journal of Sports Sciences*, **36**, 1502-1507.

Armstrong, M.J., Litvan, I., Lang, A.E., Bak, T.H., Bhatia, K.P., Borroni, B., Boxer, A.L., Dickson, D.W., Grossman, M., Hallett, M., Josephs, K.A., Kertesz, A., Lee, S.E., Miller, B.L., Reich, S.G., Riley, D.E., Tolosa, E., Troster, A.I., Vidailhet, M., & Weiner, W.J. (2013). Criteria for the diagnosis of corticobasal degeneration. *Neurology*, **80**, 496-503.

Beck, A.T., Epstein, N., Brown, G., & Steer, R.A. (1988). An inventory for measuring clinical anxiety: Psychometric properties. *Journal of Consulting and Clinical Psychology*, **56**, 893-897.

Bédard, M., Molloy, D.W., Squire, L., Dubois, S., Lever, J.A., & O'Donnell, M. (2001). The Zarit Burden Interview: a new short version and screening version. *Gerontologist*, **41**, 652-657.

Beekman, A.T., Deeg, D.J., Van Limbeek, J., Braam, A.W., De Vries, M.Z., & Van Tilburg, W. (1997). Criterion validity of the Center for Epidemiologic Studies Depression scale (CES-D): results from a community-based sample of older subjects in The Netherlands. *Psychol Med*, **27**, 231-235.

Bent, B., Goldstein, B.A., Kibbe, W.A., & Dunn, J.P. (2020). Investigating sources of inaccuracy in wearable optical heart rate sensors. *npj Digital Medicine*, **3**, 18.

Berg, L., McKeel, D.W., Jr, Miller, J.P., Baty, J., & Morris, J.C. (1993). Neuropathological Indexes of Alzheimer's Disease in Demented and Nondemented Persons Aged 80 Years and Older. *Archives of Neurology*, **50**, 349-358.

Burke, W.J., Miller, J.P., Rubin, E.H., Morris, J.C., Coben, L.A., Duchek, J., Wittels, I.G., & Berg, L. (1988). Reliability of the Washington University Clinical Dementia Rating. *Archives of Neurology*, **45**, 31-32.

Bussmann, J.B.J., Tulen, J.H.M., van Herel, E.C.G., & Stam, H.J. (1998). Quantification of physical activities by means of ambulatory accelerometry: A validation study. *Psychophysiology*, **35**, 488-496.

Butler, E.A. (2015). Interpersonal affect dynamics: It takes two (and time) to tango. *Emotion Review*, **7**, 336-341.

Chen, K.-H., Brown, C.L., Wells, J.L., Rothwell, E.S., Otero, M.C., Levenson, R.W., & Fredrickson, B.L. (2020). Physiological linkage during shared positive and shared negative emotion. *Journal of Personality and Social Psychology*, No Pagination Specified-No Pagination Specified.

Chen, K.-H., Wells, J.L., Otero, M., Lwi, S.J., Haase, C.M., & Levenson, R.W. (2017). Greater experience of negative non-target emotions in patients with neurodegenerative diseases is related to lower emotional well-being in caregivers. *Dementia and Geriatric Cognitive Disorders*, 245-255.

Coan, J.A., Kasle, S., Jackson, A., Schaefer, H.S., & Davidson, R.J. (2013). Mutuality and the social regulation of neural threat responding. *Attachment & Human Development*, **15**, 303-315.

Connelly, D.E., Verstaen, A., Brown, C.L., Lwi, S.J., & Levenson, R.W. (2020). Pronoun Use during Patient-Caregiver Interactions: Associations with Caregiver Well-Being. *Dementia and Geriatric Cognitive Disorders*, **49**, 202-209.

Cuijpers, P. (2005). Depressive disorders in caregivers of dementia patients: A Systematic review. *Aging & Mental Health*, **9**, 325-330.

Dias, R., Santos, R.L., Sousa, M.F., Nogueira, M.M., Torres, B., Belfort, T., & Dourado, M.C. (2015). Resilience of caregivers of people with dementia: a systematic review of biological and psychosocial determinants. *Trends Psychiatry Psychother*, **37**, 12-19.

Ekman, P., Levenson, R.W., & Friesen, W.V. (1983). Autonomic nervous system activity distinguishes among emotions. *Science*, **221**, 1208-1210.

Evenson, K.R., Buchner, D.M., & Morland, K.B. (2012). Objective measurement of physical activity and sedentary behavior among US adults aged 60 years or older. *Preventing chronic disease*, **9**, E26-E26.

Fydrich, T., Dowdall, D., & Chambless, D.L. (1992). Reliability and validity of the Beck Anxiety Inventory. *Journal of Anxiety Disorders*, **6**, 55-61.

Gates, K.M., Gatzke-Kopp, L.M., Sandsten, M., & Blandon, A.Y. (2015). Estimating time-varying RSA to examine psychophysiological linkage of marital dyads. *Psychophysiology*, **52**, 1059-1065.

Gorno-Tempini, M.L., Hillis, A.E., Weintraub, S., Kertesz, A., Mendez, M., Cappa, S.e., emsp14, al, Ogar, J., Rohrer, J., Black, S., & Boeve, B.F. (2011). Classification of primary progressive aphasia and its variants. *Neurology*, **76**, 1006-1014.

Haringsma, R., Engels, G.I., Beekman, A.T., & Spinhoven, P. (2004). The criterion validity of the Center for Epidemiological Studies Depression Scale (CES-D) in a sample of self-referred elders with depressive symptomatology. *Int J Geriatr Psychiatry*, **19**, 558-563.

Helm, J.L., Sbarra, D.A., & Ferrer, E. (2014). Coregulation of respiratory sinus arrhythmia in adult romantic partners. *Emotion*, **14**, 522-531.

Hess, U., & Bourgeois, P. (2010). You smile–I smile: Emotion expression in social interaction. *Biological Psychology*, **84**, 514-520.

Hua, A.Y., Wells, J.L., Brown, C.L., & Levenson, R.W. (in press). Emotional and cognitive empathy in caregivers of persons with neurodegenerative disease: Relationships with caregiver mental health. *Clinical Psychological Science*.

James, B.D., Boyle, P.A., Bennett, D.A., & Buchman, A.S. (2012). Total daily activity measured with actigraphy and motor function in community-dwelling older persons with and without dementia. *Alzheimer disease and associated disorders*, **26**, 238-245.

Julien, D., Brault, M., Chartrand, É., & Bégin, J. (2000). Immediacy behaviours and synchrony in satisfied and dissatisfied couples. *Canadian Journal of Behavioural Science / Revue canadienne des sciences du comportement*, **32**, 84-90.

Kernebeck, S., Holle, D., Pogscheba, P., Jordan, F., Mertl, F., Huldtgren, A., Bader, S., Kirste, T., Teipel, S., Holle, B., & Halek, M. (2019). A Tablet App- and Sensor-Based Assistive Technology Intervention for Informal Caregivers to Manage the Challenging Behavior of People With Dementia (the insideDEM Study): Protocol for a Feasibility Study. *JMIR Res Protoc*, **8**, e11630.

Kiecolt-Glaser, J.K., & Wilson, S.J. (2017). Lovesick: How Couples' Relationships Influence Health. *Annual Review of Clinical Psychology*, **13**, 421-443.

Kim, J., Campbell, A.S., de Ávila, B.E.-F., & Wang, J. (2019). Wearable biosensors for healthcare monitoring. *Nature Biotechnology*, **37**, 389-406.

Knuff, A., Leung, R.H., Seitz, D.P., Pallaveshi, L., & Burhan, A.M. (2019). Use of Actigraphy to Measure Symptoms of Agitation in Dementia. *The American Journal of Geriatric Psychiatry*, **27**, 865-869.

Kolanowski, A.M., Fick, D., Waller, J.L., & Shea, D. (2004). Spouses of persons with dementia: Their healthcare problems, utilization, and costs. *Research in Nursing & Health*, **27**, 296-306.

Levenson, R.W. (2007). Emotion elicitation with neurological patients. In J.A. Coan & J.J.B. Allen (Eds.), *Handbook of emotion elicitation and assessment* (pp. 158-168). New York, NY: Oxford University Press.

Levenson, R.W. (2014). The Autonomic nervous system and emotion. *Emotion Review*, **6**, 100-112.

Levenson, R.W., & Gottman, J.M. (1983). Marital interaction: Physiological linkage and affective exchange. *Journal of Personality and Social Psychology*, **45**, 587-597.

Litvan, I., Agid, Y., Calne, D., Campbell, G., Dubois, B., Duvoisin, R.C., Goetz, C.G., Golbe, L.I., Grafman, J., Growdon, J.H., Hallett, M., Jankovic, J., Quinn, N.P., Tolosa, E., & Zee, D.S. (1996). Clinical research criteria for the diagnosis of progressive supranuclear palsy (Steele-Richardson-Olszewski syndrome): Report of the NINDS-SPSP international workshop. *Neurology*, **47**, 1-9.

Liu, S., Rovine, M.J., Cousino Klein, L., & Almeida, D.M. (2013). Synchrony of diurnal cortisol pattern in couples. *Journal of Family Psychology*, **27**, 579-588.

Locke, H.J., & Wallace, K.M. (1959). Short Marital-Adjustment and Prediction Tests: Their Reliability and Validity. *Marriage and Family Living*, **21**, 251-255.

Lwi, S.J., Casey, J.J., Verstaen, A., Connelly, D.E., Merrilees, J., & Levenson, R.W. (2018). Genuine smiles by patients during marital interactions are associated with better caregiver mental health. *The Journals of Gerontology: Series B*, **74**, 975-987.

Marci, C.D., Ham, J., Moran, E., & Orr, S.P. (2007). Physiologic correlates of perceived therapist empathy and social-emotional process during psychotherapy. *The Journal of nervous and mental disease*, **195**, 103-111.

McKhann, G.M., Knopman, D.S., Chertkow, H., Hyman, B.T., Jack Jr, C.R., Kawas, C.H., Klunk, W.E., Koroshetz, W.J., Manly, J.J., & Mayeux, R. (2011). The diagnosis of dementia due to Alzheimer's disease: Recommendations from the National Institute on

Aging-Alzheimer's Association workgroups on diagnostic guidelines for Alzheimer's disease. *Alzheimer's & Dementia*, **7**, 263-269.

Morris, J.C. (1993). The Clinical Dementia Rating (CDR): Current version and scoring rules. *Neurology*, **43**, 2412-2414.

O'Rourke, N., & Tuokko, H.A. (2003). Psychometric Properties of an Abridged Version of the Zarit Burden Interview Within a Representative Canadian Caregiver Sample. *The Gerontologist*, **43**, 121-127.

Obayashi, K., Saeki, K., & Kurumatani, N. (2014). Association between light exposure at night and insomnia in the general elderly population: The HEIJO-KYO cohort. *Chronobiology International*, **31**, 976-982.

Obrist, P.A., Webb, R.A., Sutterer, J.R., & Howard, J.L. (1970). The cardiac-somatic relationship: some reformulations. *Psychophysiology*, **6**, 569-587.

Palumbo, R.V., Marraccini, M.E., Weyandt, L.L., Wilder-Smith, O., McGee, H.A., Liu, S., & Goodwin, M.S. (2016). Interpersonal autonomic physiology: A Systematic review of the literature. *Personality and Social Psychology Review*, **21**, 99-141.

Patterson, S.M., Krantz, D.S., Montgomery, L.C., Deuster, P.A., Hedges, S.M., & Nebel, L.E. (1993). Automated physical activity monitoring: Validation and comparison with physiological and self-report measures. *Psychophysiology*, **30**, 296-305.

Pauly, T., Keller, J., Knoll, N., Michalowski, V.I., Hohl, D.H., Ashe, M.C., Gerstorf, D., Madden, K.M., & Hoppmann, C.A. (2019). Moving in Sync: Hourly Physical Activity and Sedentary Behavior are Synchronized in Couples. *Annals of Behavioral Medicine*, **54**, 10-21.

Pauly, T., Michalowski, V.I., Drewelies, J., Gerstorf, D., Ashe, M.C., Madden, K.M., & Hoppmann, C.A. (2020). Cortisol Synchrony in Older Couples: Daily Socioemotional Correlates and Interpersonal Differences. *Psychosomatic Medicine*, **82**, 669-677.

Petersen, R.C. (2004). Mild cognitive impairment as a diagnostic entity. *Journal of Internal Medicine*, **256**, 183-194.

Pinquart, M., & Sörensen, S. (2003). Differences between caregivers and noncaregivers in psychological health and physical health: A meta-analysis. *Psychology and aging*, **18**, 250-267.

Poole, L., Steptoe, A., Wawrzyniak, A.J., Bostock, S., Mitchell, E.S., & Hamer, M. (2011). Associations of objectively measured physical activity with daily mood ratings and psychophysiological stress responses in women. *Psychophysiology*, **48**, 1165-1172.

Radloff, L.S. (1977). The CES-D scale: A self-report depression scale for research in the general population. *Applied Psychological Measurement*, **1**, 385-401.

Rascovsky, K., Hodges, J.R., Knopman, D., Mendez, M.F., Kramer, J.H., Neuhaus, J., van Swieten, J.C., Seelaar, H., Dopper, E.G.P., Onyike, C.U., Hillis, A.E., Josephs, K.A., Boeve, B.F., Kertesz, A., Seeley, W.W., Rankin, K.P., Johnson, J.K., Gorno-Tempini, M.-L., Rosen, H., Prioleau-Latham, C.E., Lee, A., Kipps, C.M., Lillo, P., Piguet, O., Rohrer, J.D., Rossor, M.N., Warren, J.D., Fox, N.C., Galasko, D., Salmon, D.P., Black, S.E., Mesulam, M., Weintraub, S., Dickerson, B.C., Diehl-Schmid, J., Pasquier, F., Deramecourt, V., Lebert, F., Pijnenburg, Y., Chow, T.W., Manes, F., Grafman, J., Cappa, S.F., Freedman, M., Grossman, M., & Miller, B.L. (2011). Sensitivity of revised diagnostic criteria for the behavioural variant of frontotemporal dementia. *Brain*, **134**, 2456-2477.

Reed, R.G., Randall, A.K., Post, J.H., & Butler, E.A. (2013). Partner influence and in-phase versus anti-phase physiological linkage in romantic couples. *International Journal of Psychophysiology*, **88**, 309-316.

Saxbe, D., & Repetti, R.L. (2010). For better or worse? Coregulation of couples' cortisol levels and mood states. *Journal of Personality and Social Psychology*, **98**, 92.

Schulz, R., Beach, S.R., Czaja, S.J., Martire, L.M., & Monin, J.K. (2020). Family Caregiving for Older Adults. *Annual Review of Psychology*, **71**, 635-659.

Schulz, R., O'Brien, A.T., Bookwala, J., & Fleissner, K. (1995). Psychiatric and physical morbidity effects of dementia caregiving: prevalence, correlates, and causes. *Gerontologist*, **35**, 771-791.

Seppala, E., Rossomando, T., & Doty, J.R. (2013). Social connection and compassion: Important predictors of health and well-being. *Social Research*, **80**, 411-430.

Tassinary, L.G., Cacioppo, J.T., & Vanman, E.J. (2007). The Skeletomotor system: Surface electromyography. In J.T. Cacioppo, L.G. Tassinary, & G. Berntson (Eds.), *Handbook of Psychophysiology* (pp. 267 - 302). New York: Cambridge University Press.

Teng, E., Marshall, G.A., & Cummings, J.L. (2011). Neuropsychiatric features of dementia. In B.L. Miller & B.F. Boeve (Eds.), *The behavioral neurology of dementia* (pp. 85–100). Cambridge, UK: Cambridge University Press.

Valembois, L., Oasi, C., Pariel, S., Jarzebowski, W., Lafuente-Lafuente, C., & Belmin, J. (2015). Wrist actigraphy: A simple way to record motor activity in elderly patients with dementia and apathy or aberrant motor behavior. *The journal of nutrition, health & aging*, **19**, 759-764.

Wells, J.L., Brown, C.L., Hua, A.Y., Soyster, P.D., Chen, K.-H., Dokuru, D.R., Coppola, G., Haase, C.M., & Levenson, R.W. (2019). Neurodegenerative disease caregivers' 5-HTTLPR genotype moderates the effect of patients' empathic accuracy deficits on caregivers' well-being. *The American Journal of Geriatric Psychiatry*, **27**, 1046-1056.

Zarit, S., Orr, N.K., & Zarit, J.M. (1985). *The hidden victims of Alzheimer's disease: Families under stress*. New York: NYU Press.

AUTHOR NOTES

CONFLICT OF INTEREST

None of the authors have known financial interests or potential conflicts of interest to disclose.

TABLES

Table 1. *Descriptive statistics for demographic, functional, relationship, activity, and data inclusion/exclusion information.*

	N	*Mean*	*SE*	*SD*	*Min.*	*Max.*
PWND						
Diagnosis						
Behavioral-variant frontotemporal dementia (bvFTD)	5					
Semantic variant primary progressive aphasia (svPPA)	4					
Nonfluent variant primary progressive aphasia (nfvPPA)_	2					
Alzheimer's disease (AD)	6					
Progressive supranuclear palsy (PSP)	2					
Cortical basal syndrome (CBS)	1					
Parkinson's disease (PD)	1					
Mild cognitive impairment (MCI)	1					
Demographics						
Age		64.86	1.62	7.61	55	77
Sex	15 F, 7 M					
Dementia severity						
CDR-Total		0.77	0.11	0.51	0	2
CDR-Box		4.45	0.54	2.54	0	10
Activity (somatic) during the study						
Daily average		234.33	24.47	114.78	52.04	434.76
Max. length of being constantly inactive (zeros), minutes		20.32	1.41	6.60	9	33
Caregiver						
Demographics						
Age		61.59	1.91	8.95	44	78
Sex	7 F, 15 M					
Employment status						
Working full time	7					
Working part time	5					
Unemployed	1					
Retired	6					

Other work status	3				
Working hours and caregiving burden					
Weekly working hours		24.28	4.92	22.00	0	65
Caregiving burden		16.38	2.17	9.94	3	38
Activity (somatic) during the study					
Daily average		285.11	21.33	100.04	133.68	472.72
Max. length of being inactive (zeros), minutes		16.50	2.54	11.91	6	61

PWND-Caregiver

Relationship					
Spouse	21				
Unmarried partner	1				
Length of marriage, years		30.71	3.65	16.71	2.20	56.39
Data inclusion and exclusion					
Days included in analyses		5.41	0.24	1.14	2	7
Hours per day included in analyses		13.13	0.32	1.51	10.18	15.19
Total number of minutes that both partners were inactive throughout the 10-minute analytic window		0.59	0.42	1.97	0	9

Table 2. *Pearson correlation coefficients between PWND-caregiver activity linkage and potential confounding variables.*

	In-phase		Anti-phase	
	r	*p*	*r*	*p*
PWND				
Demographics				
Age	-0.12	0.593	0.16	0.492
Sex	0.04	0.864	0.13	0.576
Dementia severity				
CDR-Box	0.15	0.507	-0.18	0.422
Activity (somatic) during the study				
Daily average	0.07	0.760	0.10	0.659
Max. length of being inactive (zeros), minutes	-0.16	0.490	0.02	0.933
Caregiver				
Demographics				
Age	0.07	0.748	0.08	0.740
Sex	-0.04	0.864	-0.13	0.576
Employment status				
Working full time	-0.19	0.39	0.29	0.19
Working part time	0.14	0.53	-0.12	0.61
Unemployed	-0.14	0.54	0.01	0.98
Retired	0.16	0.49	-0.27	0.22
Other work status	-0.03	0.89	0.10	0.66
Working hours and caregiving burden				
Weekly working hours	-0.24	0.301	0.34	0.138
Caregiving burden	-0.18	0.443	0.13	0.571
Activity (somatic) during the study				
Daily average	-0.05	0.822	0.09	0.678
Max. length of being inactive (zeros), minutes	-0.08	0.709	-0.05	0.835
PWND-caregiver				
Relationship				

Length of marriage, years	-0.12	0.621	0.32	0.161
Data inclusion and exclusion				
Days included in analyses	-0.37	0.091	0.31	0.161
Hours per day included in analyses	0.18	0.413	-0.13	0.568
Total number of minutes that both partners were inactive throughout the 10-minute analytic window	0.01	0.977	-0.18	0.426

Notes: For the Sex, female was coded as 1 and male was coded as 2. For the five employment status categories, yes was coded as 1 and no was coded as 0.

Table 3. *Summary of regression analyses to examine the association between PWND activity, caregiver activity, and PWND-caregiver in-phase activity linkage (independent variables) and caregiver anxiety (dependent variable).*

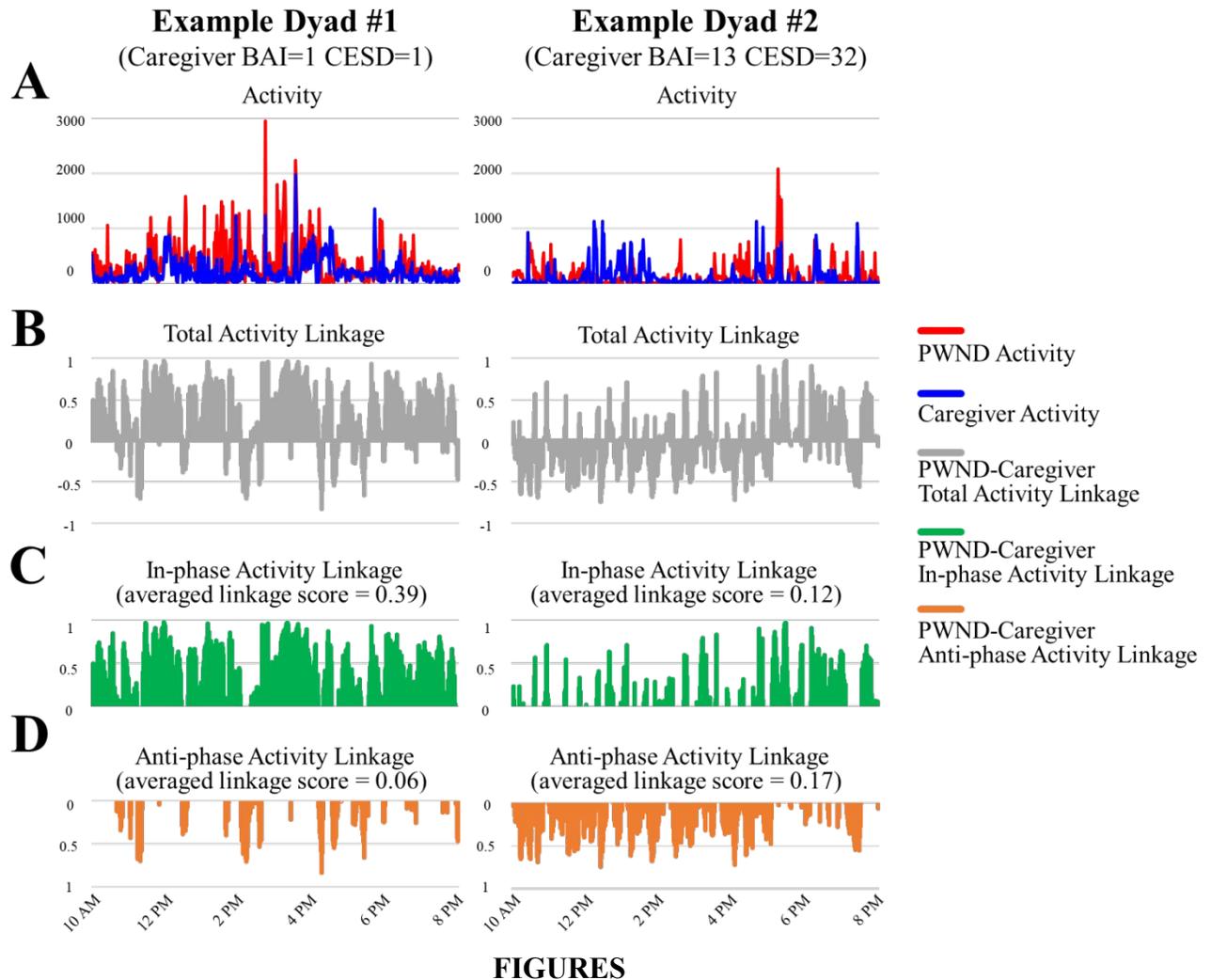| Independent Variables	Coefficients				
	Standardized Coefficients			95% CI	
	β	*t*	*p*	Lower Bound	Upper Bound
PWND activity	-0.34	-1.73	0.100	-0.05	0.01
Caregiver activity	0.00	0.02	0.987	-0.03	0.03
PWND-caregiver activity linkage	-0.43	-2.21	0.041	-247.30	-5.98

Table 4. *Summary of regression analysis to examine the unique value of PWND-caregiver in-phase activity linkage (independent variable #1) to caregiver burden (independent variables #2) in explaining caregiving anxiety (dependent variable).*

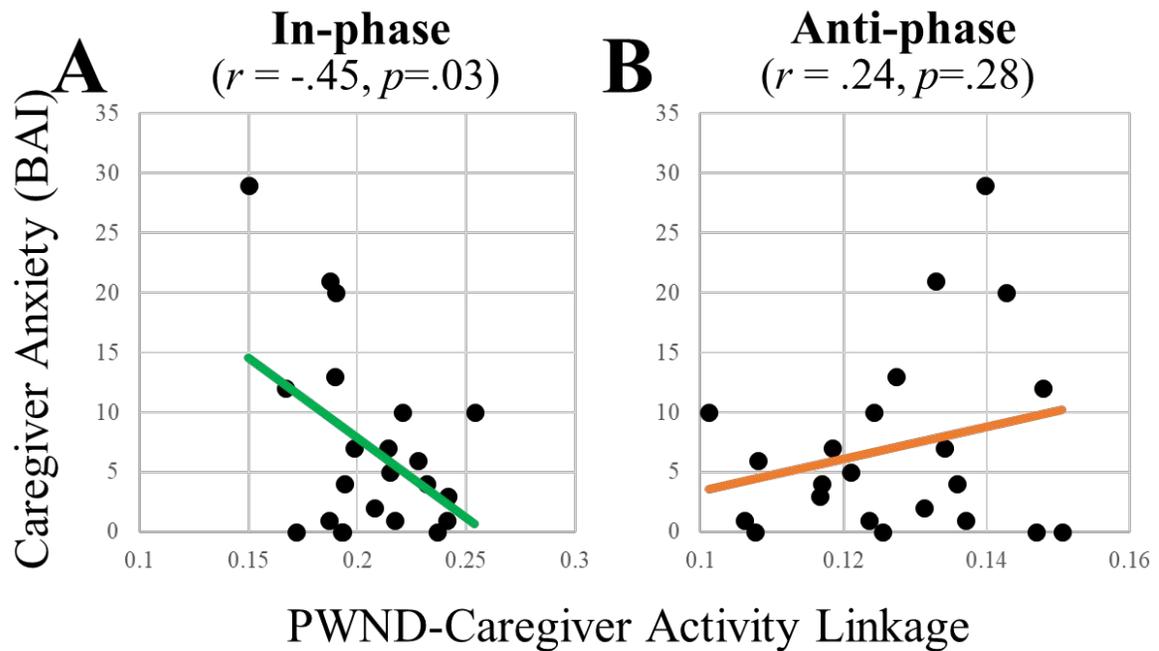|									
						Coefficients			
Model	**Model Summary**					**Standardized Coefficients**			**95% CI**	
	R^2	ΔR^2	ΔF	$p\,(\Delta F)$	**Independent Variables**	β	t	p	**Lower Bound**	**Upper Bound**
1	0.28	0.28	7.41	0.014	**Caregiver burden**	0.53	2.72	0.014	0.10	0.74
2	0.49	0.21	7.37	0.014	**Caregiver burden**	0.45	2.62	0.017	0.07	0.64
					PWND-caregiver activity linkage	-0.46	-2.71	0.014	-248.00	-31.59

FIGURES CAPTIONS

Figure 1. Illustration of (A) activity and (B-D) activity linkage (including total linkage, in-phase linkage, and anti-phase linkage) using example data from two study couples over 10 hours in their homes. The couple on the left panels had a relatively high in-phase activity linkage (averaged $r = 0.39$), and the caregiver was relatively healthy (BAI = 1, CSED = 1). In contrast, the couple on the right panels had a relatively low in-phase activity linkage (averaged $r = 0.12$), and the caregiver reported more anxiety and depressive symptoms (BAI = 13, CSED = 32).

Figure 2. Scatter plots illustrating the associations between PWND-caregiver activity (A) in-phase linkage and (B) anti-phase linkage and caregiver anxiety.

FIGURES

Figure 1. Illustration of (A) activity and (B-D) activity linkage (including total linkage, in-phase linkage, and anti-phase linkage) using example data from two study couples over 10 hours in their homes. The couple on the left panels had a relatively high in-phase activity linkage (averaged *r* = 0.39), and the caregiver was relatively healthy (BAI = 1, CSED = 1). In contrast, the couple on the right panels had a relatively low in-phase activity linkage (averaged *r* = 0.12), and the caregiver reported more anxiety and depressive symptoms (BAI = 13, CSED = 32).

Figure 2. Scatter plots illustrating the associations between PWND-caregiver activity (A) in-phase linkage and (B) anti-phase linkage and caregiver anxiety.