Day-to-day variability of multiple sensor-based physical activity parameters in older persons with dementia

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ABSTRACT

Objective: To investigate the day-to-day variability of various sensor-based physical activity (PA) parameters and to analyze effects of weekdays vs. weekend days as well as the influence of concomitant factors (gender, living conditions, cognitive status, physical performance, and level of PA) in multi-morbid, older persons with mild-to-moderate stage dementia.
Methods: In 53 participants, PA was recorded on three consecutive days. Day-to-day variability was estimated by calculating intraclass correlation coefficients (ICCs) for two consecutive days each (Friday-Saturday, Saturday-Sunday).
Results: Almost all non-walking parameters (lying time, sitting time, standing time, active time, inactive time, and sit-to-stand transitions) showed a consistently low day-to-day variability for Friday-Saturday as well as Saturday-Sunday (ICCs: .60–.96) and hence remained almost unaffected by specific days of the week and concomitant factors. Only the sub-analysis by level of PA revealed slightly deviating results (ICCs: .38–.89). The walking parameters (walking time, walking episodes, and steps) revealed a higher day-to-day variability for Friday-Saturday (ICCs: .01–.40) and a generally lower variability for Saturday-Sunday (ICCs: −.08 − .88), also depending on the respective concomitant factors.
Conclusions: Two consecutive days are adequate to reliably assess non-walking parameters, whereas walking parameters showed higher day-to-day variability with a relevant influence of type of days and concomitant factors.

1. Introduction

Older adults spend most of their days in a sitting or lying position (Harvey, Chastin, & Skelton, 2013). Such sedentary behavior becomes particularly apparent in vulnerable populations such as older persons with dementia, who are sedentary for at least two-thirds of the day (van Alphen et al., 2016) and whose activity patterns are not easy to document.

Self-report questionnaires represent commonly used methods to assess physical activity (PA) in older persons although they require sustained cognitive abilities such as recall (Ainsworth, Cahalin, Buman, & Ross, 2015) or working memory, which are limited in cognitively impaired persons (Warms, 2006). Driven by a dynamical technological progress, the questionnaire-based assessment of PA is more and more replaced by a large number of objective, sensor-based technical devices (pedometers, uni- and multiaxial accelerometers, and multi-sensor-systems), which, due to underlying evaluation algorithms and statistical evaluation methods, lead to an increasing variety of available outcome parameters (e.g. stepping/walking, posture, transitions, energy expenditure; Hubble, Naughton, Silburn, & Cole, 2015).

PA is no longer just a single score or the classification into sedentary and active behavior, but consists of many different parameters as well as more advanced approaches, such as investigating the sequences of transitions between these typically reported behavioral postures (Ghosh et al., 2018). The opportunity to investigate PA in particular parameters, however, also implies new methodological problems. A

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systematic review on 134 studies that assessed sensor-based PA parameters in older adults revealed an extraordinary large range of the assessment period from two to 450 days, whereof 56 studies reported a measurement period of seven days (Taraldsen, Chastin, Riphagen, Vereijken, & Helbostad, 2012). However, the measurement duration is often not or only inadequately reasoned.

In order to minimize the burden of assessment for older persons while increasing compliance and cost efficiency, it is important to keep the wear time of the sensor as low as possible (Trost, McIver, & Pate, 2005). Analyzing the day-today variability of sensor-based PA parameters represents an adequate method to ascertain the minimum required measurement duration to assess habitual PA. Previous investigations of the day-to-day variability in older adults, slightly different regarding age and activity level (number of steps), revealed different results for various accelerometer- and pedometer-based PA parameters (e. g. number of activity counts, number of steps, sitting duration; Hart, Swartz, Cashin, & Strath, 2011; Rowe, Kemble, Robinson, & Mahar, 2007; van Schooten et al., 2015). Therefore, these various PA parameters as well as different samples obviously require different measurement periods, usually ranging from two to five days.

Persons with dementia are a distinct and most vulnerable population that is often affected by multi-morbidity (von Renteln-Kruse et al., 2015), functional impairment (Njegovan, Hing, Mitchell, & Molnar, 2001), and mobility disorders such as reduced gait speed (van Iersel, Hoefsloot, Munneke, Bloem, & Olde Rikkert, 2004) and shortened step length (Verghese et al., 2002). Furthermore, these persons often reveal mental and behavioral symptoms such as depression, agitation, and apathy (Aalten et al., 2007), which affect activity behavior (David et al., 2012; Sabia et al., 2017; van Alphen et al., 2016) and thus potentially also the day-to-day variability of PA parameters. Previous findings on the day-to-day variability and the required measurement duration of sensor-based PA parameters in older persons are, however, based on studies that either did not report the cognitive status of the samples (de la Camara, Higueras-Fresnillo, Martinez-Gomez, & Veiga, 2018; Hart et al., 2011; Rowe et al., 2007) or have examined only a mixed sample of older persons with and without cognitive impairment (van Schooten et al., 2015). To the authors' knowledge, no previous study analyzed the day-to-day variability of individual sensor-based PA parameters in a specific sample of older persons with dementia. Therefore, the following questions still remain to be answered: a) how many measurement days are minimally required for the growing multitude of sensor-based PA parameters in older adults with dementia and b) whether this minimum of needed measurement duration is identical or different for the particular PA parameters.

Apart from the day-to-day variability and the minimum needed measurement duration of sensor-based PA parameters in older persons with dementia, it is also important to know whether specific days of the week, such as weekdays or weekend days, and various concomitant factors, such as gender, living conditions (independent vs. institutionalized), cognitive status, physical performance, or amount of PA, may influence this variability and thus the minimum required measurement period. As multi-morbid, older persons depend on social contacts and support (Edelbrock et al., 2001), it is conceivable that social routines (e. g. support to go shopping, attend social meetings), which can differ between weekdays and weekend days, affect the PA and its day-to-day variability. Previous studies have reported a heterogeneous influence of gender on the day-to-day variability of sensor-based PA parameters in children (Fairclough, Butcher, & Stratton, 2007), adults (Donaldson, Montoye, Tuttle, & Kaminsky, 2016), and older persons (de la Camara et al., 2018). Furthermore, in older adults, it has been shown that intra-individual variability of PA across days was influenced by the amount of PA, but not by the cognitive status (Watts, Walters, Hoffman, & Templin, 2016). Even though the amount of PA seems negatively related to the variability of sensor-based PA in older persons (Watts et al., 2016), the potential influence of factors directly related to low amounts of PA such as poor physical performance

(Buckinx et al., 2017) or being institutionalized (van Alphen et al., 2016) on the day-to-day variability have not yet been examined in older persons with dementia.

Primary aim of this study was to determine the day-to-day variability of various, sensor-based PA parameters in multi-morbid, older adults with mild-to-moderate stage dementia and the thereby potentially resulting minimum number of required measurement days. A secondary aim was to analyze the effects of weekdays vs. weekend days and the potential influence of concomitant factors by subgroup analyses.

2. Methods

2.1. Study design

This study is an observational study which retrospectively analyzed baseline PA data from a double-blinded, randomized, placebo-controlled trial that aimed to improve motor-cognitive functions in persons with mild-to-moderate dementia. The trial was approved by the ethics committee of the Medical Faculty of the University of Heidelberg and performed according to the declaration of Helsinki.

2.2. Study population

Participants were recruited from rehabilitation wards of a geriatric hospital, from nursing homes, and from a community-dwelling population. Inclusion criteria were age ≥ 65 years, ability to walk 10 m without aid, living within 15 km of the study site, no terminal or uncontrolled somatic and/or psychiatric diseases, and written informed consent or consent of legal guardian (if assigned). Individuals who met these criteria were examined for cognitive impairment using the Mini-Mental State Examination (MMSE; O'Bryant et al., 2008). Subsequently, eligible persons with MMSE scores of 17–26 indicating cognitive impairment underwent a further dementia diagnosis including anamnesis, neuroimaging, a comprehensive assessment based on an established neuropsychological test battery (Consortium to Establish a Registry for Alzheimer's Disease [CERAD]; Morris, Mohs, Rogers, Fillenbaum, & Heyman, 1988), a modified trail making test (ZVT-G; Oswald & Fleischmann, 1997), and a digit-span test (ZN-G; Oswald & Fleischmann, 1997). Only persons who met the core criteria for all-cause dementia (McKhann et al., 2011) evaluated by a geriatrician were included in the study.

2.3. Measurements

Age, gender, living condition (independent vs. institutionalized), number of diagnoses, and number of medications were obtained from patient charts. Cognition (MMSE), education (years of school and professional education), depression (Geriatric Depression Scale [GDS], 15-item version; Gauggel & Birkner, 1999), health-related quality of life (12-item Short Form Health Survey [SF-12]; Ware, Kosinski, & Keller, 1996), falls related self-efficacy (Short Falls Efficacy Scale International [short-FES-I]; Hauer et al., 2011), a one-item question on fear of falling (fear vs. no fear; Maki, Holliday, & Topper, 1991), and a self-reported history of falls throughout the previous year (fall vs. no fall) were attained by standardized interviewing or testing by trained assessors. A fall was defined as "an unexpected event in which the participants come to rest on the ground, floor, or lower level" (Lamb, Jørstad-Stein, Hauer, & Becker, 2005). Physical performance was assessed with a maximum gait speed test using the GAITRite® walkway system (CIR Systems Inc., Franklin, NJ, USA), the five-chair-stand (Guralnik et al., 1994), the Performance Oriented Mobility Assessment (POMA; Tinetti, 1986), and the Timed "Up and Go" Test (TUG; Podsiadlo & Richardson, 1991).

Since previous results in older persons, only a little different in terms of age and activity level, reported two to five days as adequate

measurement period (Hart et al., 2011; Rowe et al., 2007; van Schooten et al., 2015) and revealed heterogeneous findings regarding differences of average PA between single days (e. g. weekdays vs. weekend days; Nicolai et al., 2010; Rowe et al., 2007), PA was recorded on three consecutive days (Friday, Saturday, and Sunday) in the participants' living environment. For this purpose, a small (5.1 cm × 3 cm × 1.6 cm) and light (24 g) motion sensor (PAMSys™, BioSensics, Watertown, MA, USA) with a sample frequency of 40 Hz and a battery life up to 200 h was used. The sensor attachment (with a chest strap on the sternum) was verified two times a day (at morning and evening), and replaced if necessary. The sensor contained a 3-axis accelerometer to identify posture, gait, and postural transitions with high specificity and sensitivity of 87–99.7% and 87–99% for identifying PA patterns in older adults (Najafi, Armstrong, & Mohler, 2013). Underlying analysis algorithms and their successful validation are described elsewhere (Najafi et al., 2003).

PA was reported as following parameters: lying time (hours), sitting time (hours), standing time (hours), walking time (hours), active time (sum of standing and walking time; hours), inactive time (sum of lying and sitting time; hours), sit-to-stand transitions (STS; number), walking episodes (number), and steps (number).

2.4. Statistical analysis

All demographic and clinical characteristics were described as means ± standard deviations, or number of cases and percentages. PA records were separated into 24 -h periods. In cases, where the full 24 h per day could not be recorded for different reasons, such as premature removal of the sensor by the participants, the missing time period was interpolated by linear interpolation. To examine the day-to-day variability of the PA parameters, the inter-day reliability (high reliability is equivalent to low variability and vice versa) was estimated by calculating intraclass correlation coefficients (ICCs) using a two-way random-effects model (absolute agreement, single measures). ICCs ≥ .70 were considered as minimal requirement for an adequate day-to-day reliability on a group level (Aaronson et al., 2002). These analyses were carried out in the total group and in predefined subgroups for two potentially different combinations of consecutive days, weekday-weekend day (Friday-Saturday) and weekend day-weekend day (Saturday-Sunday). Subgroups were categorized by following dichotomous characteristics: gender (women vs. men), living condition (independent vs. institutionalized), cognitive status (MMSE Score: ≥ 24 points vs. < 24 points; Folstein, Folstein, & McHugh, 1975), physical performance (five-chair-stand: ≥ 12 s vs. < 12 s [Tiedemann, Shimada, Sherrington, Murray, & Lord, 2008]; maximum gait speed: ≥ 1.04 m/s vs. < 1.04 m/s), and activity level (sum of standing and walking time averaged per day: ≥ 3.4 h vs. < 3.4 h). The dichotomous characteristics were defined by subgroup characteristics (gender, living conditions), established cut-offs given in the literature (MMSE, five-chair-stand), or sample specific median values (maximum gait speed, activity level).

To describe the investigating context and to ascertain whether the PA parameters in the total group showed structural differences between measured days at the group level, a repeated measures analysis of variance (ANOVA) was used. In case of violating the assumption of sphericity, the Greenhouse-Geisser correction was applied. If a significant level was revealed, a post hoc test with Bonferroni correction was used to identify the differences between the respective days.

Effect sizes were calculated as partial eta squared (η_p^2). Values ranging from .01 to .06 indicate small, values from .06 to .14 medium, and values above .14 large effect sizes (Cohen, 1988). All statistical analyses were performed using Statistical Package for Social Sciences (SPSS) version 25.0 (IBM, Armonk, NY, USA). The significance level was set at $p \leq .05$.

Table 1
Descriptive characteristics of the study participants.

Variable	n (%)	Mean (SD)
Age (years)		82.3 (5.6)
Gender (women)	39 (73.6)	
Living condition (institutionalized)	15 (28.3)	
Education (years)		11.8 (3.4)
Diagnoses (number)		8.1 (4.1)
Medications (number)		7.0 (3.2)
MMSE (sum score)		22.1 (2.9)
GDS (sum score)		3.30 (2.33)
SF-12 (total score)		91.8 (14.0)
Short FES-I (sum score)		9.74 (2.98)
One-item question on fear of falling (fear)	24 (45.3)	
Participants with at least one fall in the previous year	32 (60.4)	
Physical status		
Five-chair-stand (seconds)		14.8 (6.7)
Maximum gait speed (meter/second)		1.05 (0.37)
POMA (total score)		22.2 (3.8)
TUG (seconds)		17.0 (7.2)
Physical activity[a]		
Lying time per day (hours)		9.1 (3.4)
Sitting time per day (hours)		11.3 (3.3)
Standing time per day (hours)		3.1 (1.2)
Walking time per day (hours)		0.53 (0.42)
Active time per day (hours)		3.6 (1.6)
Inactive time per day (hours)		20.4 (1.6)
Walking episodes per day (number)		64.9 (50.3)
Steps per day (number)		1536 (1262)
STS per day (number)		134 (58)

Note. Presented are descriptive characteristics for the study sample of multimorbid persons with mild-to-moderate stage dementia (*N* = 53). Data are mean (*SD*) or number (%). *n* = Number of Cases; *SD* = Standard Deviation; MMSE = Mini-Mental State Examination; GDS = Geriatric Depression Scale (15 items); SF-12 = 12-item Short Form Health Survey; Short FES-I = Short Falls Efficacy Scale-International; POMA = Performance Oriented Mobility Assessment; TUG = Timed-Up-and-Go-Test; Active time per day = sum of standing and walking time; Inactive time = sum of lying and sitting time; STS = Sit-to-Stand Transitions.

[a] Mean over the three measurement days, interpolation: day 1 (*n* = 0), day 2 (*n* = 1), day 3 (*n* = 19).

3. Results

The study sample included 53 persons comprising multi-morbid, older persons with mild-to-moderate dementia. Mean age was 82.3 ± 5.6 years, almost three quarters (73.6%) were women, and more than a quarter (28.3%) were living in nursing homes (Table 1). The mean time of activity recording per day was 23.95 ± 0.25 h, indicating a good adherence to the wearing time of the sensor.

3.1. Day-to-day variability of physical activity parameters

In the total group, all non-walking parameters (lying time, sitting time, number of STS, active time, inactive time, and standing time) revealed a rather low day-to-day variability and exceeded the required cut-off for acceptable reliability for both combinations of consecutive days, Friday-Saturday (ICC = .73-.85) and Saturday-Sunday (ICC = .81-.85, Table 2). Regarding the walking parameters, the ICC of walking time (ICC = .69) and of number of walking episodes (ICC = .70) for Saturday-Sunday was marginally below or equal to the cut-off value. Even though the ICC of number of steps was higher for Saturday-Sunday (ICC = .49) than for Friday-Saturday (ICC = .18), the reliability was not adequate to achieve a value greater than or equal to the cut-off. None of the walking parameters met this requirement for Friday-Saturday (ICC = .15–.28).

Table 2

Intraclass correlation coefficients of physical activity parameters for two different combinations of consecutive days of the week.

Parameter	Friday - Saturday	Saturday - Sunday
Lying time (hours)	**.85** [.75, .91]	**.83** [.73, .90]
Sitting time (hours)	**.84** [.73, .90]	**.85** [.75, .91]
STS (number)	**.82** [.71, .89]	**.85** [.76, .91]
Active time (hours)	**.82** [.71, .89]	**.83** [.72, .90]
Inactive time (hours)	**.82** [.71, .89]	**.83** [.72, .90]
Standing time (hours)	**.73** [.49, .85]	**.81** [.69, .88]
Walking time (hours)	.28 [−.09, .57]	.69 [.52, .81]
Walking episodes (number)	.15 [−.08, .39]	**.70** [.54, .82]
Steps (number)	.18 [−.07, .42]	.49 [.26, .67]

Note. Presented are intraclass correlation coefficients (ICCs) including 95% confidence intervals of different physical activity parameters for comparisons between different combinations of consecutive days (Friday-Saturday vs. Saturday-Sunday) in the total group ($N = 53$). ICCs $\geq$ .70 (shown in boldface) are considered acceptable for day-to-day reliability. STS = Sit-to-Stand Transitions; Active time = sum of standing and walking time; Inactive time = sum of lying and sitting time.

3.2. Mean value comparisons of physical activity parameters between days

In addition to estimating the individual day-to-day variability, the sensor-derived parameters were tested for mean value differences between measurement days to obtain whether there were structural differences of PA between individual days at the group level. The results of a repeated measures ANOVA revealed significant differences between Friday, Saturday, and Sunday in the PA parameters standing time, $F(2, 104) = 12.4$, $p < .001$, $\eta_p^2 = .19$; walking time, $F(1.42, 73.8) = 78.0$, $p < .001$, $\eta_p^2 = .60$; number of walking episodes, $F(1.11, 57.5) = 69.5$, $p < .001$, $\eta_p^2 = .57$; and number of steps, $F(1.40, 73.0) = 50.2$, $p < .001$, $\eta_p^2 = .49$. The effect sizes were large for all comparisons (all $\eta_p^2 \geq .19$). No significant differences were observed in the sensor-based PA parameters lying time, sitting time, number of STS, active time, and inactive time. Post hoc tests using Bonferroni correction determined following pairwise comparisons: Standing time was significantly lower on Friday (165 ± 79 min) compared to Saturday (194 ± 79 min, $p = .001$) and Sunday (198 ± 82 min, $p < .001$). Walking time was significantly higher on Friday (60 ± 40 min) compared to Saturday (20 ± 24 min, $p < .001$) and Sunday (17 ± 21 min, $p < .001$). Number of walking episodes was significantly higher on Friday (137 ± 107) compared to Saturday (30 ± 34, $p < .001$) and Sunday (28 ± 31, $p < .001$). Number of steps was significantly higher on Friday (2993 ± 2314) compared to Saturday (913 ± 1402, $p < .001$) and Sunday (703 ± 922, $p < .001$). No significant differences were found between Saturday and Sunday.

3.3. Day-to-day variability of physical activity parameters in subgroups

When assessing the day-to-day variability of the PA parameters in subgroups, almost all non-walking parameters met the requirement for acceptable day-to-day reliability for Friday-Saturday and Saturday-Sunday, with minor exceptions especially in the subgroup activity level. The reliability values of the walking parameters were less conclusive and depended on the respective subgroup, dichotomous characteristic of the subgroup, or combination of consecutive days. While the analyses did not show adequate reliability values in the walking parameters for Friday-Saturday in all subgroups, the reliability for Saturday-Sunday varied between the subgroups and dichotomous characteristics (Table 3).

4. Discussion

Study results documented that non-walking parameters (e. g. lying time, sitting time) revealed a low day-to-day variability and remained less affected by specific days (weekday vs. weekend day) and concomitant factors (gender, living conditions, cognitive status, physical performance, activity level) in multi-morbid, older persons with mild-to-moderate stage dementia. Walking parameters generally revealed a higher day-to-day variability between different types of days (Friday-Saturday) and, also depending on the concomitant factor, a lower day-to-day variability between similar days (Saturday-Sunday).

4.1. Day-to-day variability of physical activity parameters

Present results are in line with a previous study in high-functioning, community-dwelling older persons showing that day-to-day variability of walking parameters was higher compared to non-walking parameters and that two days were sufficient to reliably assess non-walking parameters (de la Camara et al., 2018). Given the high percentage of regularly documented sedentary behavior for at least two-thirds of the day (van Alphen et al., 2016), the low day-to-day variability of non-walking parameters seems not surprising. However, at a very low level of PA, only occasionally occurring periods of walking activity, even though they may be low with respect to absolute volume, may then lead to a higher intra-individual variability as documented for walking parameters in the present study. This assumption is supported by the finding of a study in a mixed sample of older community-dwellers with mild Alzheimer's disease and without cognitive impairment, in which persons with a higher average level of PA tended to be more consistent in their PA (Watts et al., 2016).

Current results regarding the measurement period of non-walking parameters complied with the findings of a previous study in a mixed sample of community-dwelling elderly with and without cognitive impairment reporting two measurement days as sufficient for non-walking parameters such as sitting time, number of STS, or standing time (van Schooten et al., 2015). In contrast, the present results of walking parameters contradict to previous studies in heterogeneous samples, either mixed (van Schooten et al., 2015) or unspecified for cognitive status (Rowe et al., 2007), which showed that two assessment days were sufficient for comparable walking parameters.

The present study indicates that the required measurement duration, in particular of walking parameters, may depend on the respective measurement days, which are therefore an important factor for the assessment of habitual physical activity.

Regarding the type of measurement days, the rather low day-to-day variability of non-walking parameters for different type of days in the current findings complies with previous studies also showing a rather low day-to-day variability of parameters representing sedentary behavior for weekdays vs. weekend days in high-functioning older adults living independently (de la Camara et al., 2018) or in continuing care retirement centers (Marshall et al., 2015). In contrast, the high day-to-day variability of walking parameters for different types of days contradicts previous results reporting a rather low day-to-day variability of walking parameters for Friday vs. Saturday (de la Camara et al., 2018). The present study revealed that the day-to-day variability of walking parameters for different types of days was strikingly different compared to similar types of days, suggesting structural differences between weekdays and weekend days with divergent daily routines and habitual patterns in older persons with mild-to-moderate stage dementia.

4.2. Mean value comparisons of physical activity parameters between days

Comparisons of the group mean values support the assumption of similar activity patterns within comparable weekend days (Saturday & Sunday) and a structural difference between different types of days (Friday vs. Saturday & Friday vs. Sunday), mainly affecting walking behavior in the specific study sample.

The present study outcomes with mean value differences in walking parameters between different types of days (weekday vs. weekend days) are in line with findings in a similar old community-dwelling

Table 3

Intraclass correlation coefficients of physical activity parameters for two different combinations of consecutive days of the week in subgroups.

Parameter	Gender				Living conditions				Cognitive status			
	women n = 39		men n = 14		independent n = 38		institutionalized n = 15		MMSE ≥ 24 pts n = 21		MMSE < 24 pts n = 32	
	Friday - Saturday	Saturday - Sunday	Friday - Saturday	Saturday - Sunday	Friday - Saturday	Saturday - Sunday	Friday - Saturday	Saturday - Sunday	Friday - Saturday	Saturday - Sunday	Friday - Saturday	Saturday - Sunday
Lying time (hours)	**.84** [.71, .91]	**.83** [.70, .91]	**.88** [.67, .96]	**.84** [.57, .95]	**.87** [.77, .93]	**.81** [.66, .90]	**.77** [.44, .92]	**.89** [.88, .96]	**.88** [.74, .95]	**.84** [.65, .93]	**.80** [.62, .90]	**.83** [.69, .92]
Sitting time (hours)	**.84** [.71, .91]	**.84** [.71, .91]	**.83** [.56, .94]	**.86** [.62, .95]	**.88** [.78, .93]	**.83** [.69, .91]	**.75** [.41, .91]	**.88** [.64, .96]	**.89** [.74, .95]	**.86** [.70, .94]	**.79** [.61, .89]	**.83** [.69, .92]
STS (number)	**.82** [.69, .90]	**.88** [.79, .94]	**.74** [.36, .91]	.65 [.23, .87]	**.77** [.61, .88]	**.81** [.66, .89]	**.90** [.74, .97]	**.94** [.84, .98]	**.82** [.61, .92]	**.81** [.59, .92]	**.82** [.67, .91]	**.88** [.77, .94]
Active time (hours)	**.83** [.69, .91]	**.85** [.72, .92]	**.81** [.51, .93]	**.80** [.48, .93]	**.80** [.65, .89]	**.77** [.60, .88]	**.86** [.61, .95]	**.95** [.87, .98]	**.87** [.71, .94]	**.84** [.64, .93]	**.77** [.58, .88]	**.83** [.68, .91]
Inactive time (hours)	**.83** [.69, .91]	**.85** [.72, .92]	**.81** [.51, .93]	**.80** [.48, .93]	**.80** [.65, .89]	**.77** [.60, .88]	**.86** [.61, .95]	**.95** [.87, .98]	**.87** [.71, .94]	**.84** [.64, .93]	**.77** [.58, .88]	**.83** [.68, .91]
Standing time (hours)	**.71** [.46, .85]	**.82** [.68, .90]	**.80** [.39, .94]	**.78** [.45, .92]	.69 [.37, .85]	**.75** [.56, .86]	**.82** [.54, .93]	**.95** [.85, .98]	**.87** [.64, .95]	**.82** [.61, .92]	.60 [.29, .79]	**.80** [.63, .90]
Walking time (hours)	.28 [-.08, .57]	.67 [.45, .81]	.28 [-.10, .68]	**.78** [.44, .93]	.28 [-.07, .57]	.62 [.39, .78]	.30 [-.10, .70]	**.88** [.68, .96]	.40 [-.10, .73]	**.83** [.63, .93]	.19 [-.09, .47]	.57 [.29, .76]
Walking episodes (number)	.20 [-.09, .48]	**.70** [.50, .83]	.11 [-.13, .47]	**.73** [.33, .91]	.16 [-.09, .42]	**.71** [.51, .84]	.13 [-.12, .49]	**.72** [.37, .90]	.25 [-.11, .59]	**.85** [.67, .94]	.06 [-.10, .28]	.55 [.26, .75]
Steps (number)	.19 [-.07, .45]	.46 [.18, .67]	.16 [-.12, .53]	.68 [.24, .89]	.15 [-.09, .41]	.37 [.07, .61]	.26 [-.12, .64]	**.83** [.56, .94]	.28 [-.10, .62]	**.78** [.54, .91]	.11 [-.12, .37]	.40 [.08, .65]

Parameter	Five-chair-stand				Maximum gait speed				Activity level			
	≥12 s n = 34		< 12 s n = 18		≥1.04 m/s n = 27		< 1.04 m/s n = 26		≥3.4 h/day n = 27		< 3.4 h/day n = 26	
	Friday - Saturday	Saturday- Sunday	Friday - Saturday	Saturday- Sunday	Friday - Saturday	Saturday- Sunday	Friday - Saturday	Saturday- Sunday	Friday - Saturday	Saturday- Sunday	Friday - Saturday	Saturday- Sunday
Lying time (hours)	**.79** [.63, .89]	**.81** [.66, .90]	**.96** [.90, .99]	**.89** [.73, .96]	**.96** [.91, .98]	**.85** [.69, .93]	.68 [.40, .84]	**.82** [.64, .92]	**.92** [.83, .96]	**.76** [.54, .88]	**.80** [.60, .90]	**.87** [.73, .94]
Sitting time (hours)	**.80** [.64, .90]	**.83** [.70, .91]	**.91** [.76, .96]	**.86** [.66, .94]	**.91** [.81, .96]	**.81** [.63, .91]	**.73** [.48, .87]	**.88** [.74, .94]	**.85** [.70, .93]	**.77** [.56, .89]	**.83** [.65, .92]	**.89** [.77, .95]
STS (number)	**.79** [.61, .89]	**.85** [.73, .92]	**.81** [.57, .92]	**.82** [.59, .93]	**.77** [.56, .89]	**.84** [.69, .93]	**.86** [.71, .93]	**.85** [.70, .93]	**.77** [.56, .89]	**.79** [.59, .90]	.64 [.35, .82]	**.79** [.59, .90]
Active time (hours)	**.79** [.62, .89]	**.83** [.69, .91]	**.78** [.51, .91]	**.79** [.53, .92]	**.78** [.57, .89]	**.83** [.66, .92]	**.82** [.64, .91]	**.79** [.59, .90]	**.72** [.47, .86]	**.70** [.44, .85]	.38 [.00, .66]	.56 [.23, .77]
Inactive time (hours)	**.79** [.62, .89]	**.83** [.69, .91]	**.78** [.51, .91]	**.79** [.53, .92]	**.78** [.57, .89]	**.83** [.66, .92]	**.82** [.64, .91]	**.79** [.59, .90]	**.72** [.47, .86]	**.70** [.44, .85]	.38 [.00, .66]	.56 [.23, .77]
Standing time (hours)	.67 [.33, .84]	**.83** [.68, .91]	**.71** [.39, .88]	**.75** [.44, .90]	**.70** [.41, .86]	**.80** [.61, .90]	**.70** [.37, .86]	**.77** [.55, .89]	.54 [.14, .78]	.63 [.33, .81]	.40 [.05, .67]	.60 [.30, .80]
Walking time (hours)	.31 [-.10, .67]	**.74** [.53, .86]	.16 [-.14, .51]	.61 [.23, .83]	.18 [-.10, .48]	.64 [.35, .82]	.37 [-.10, .73]	**.76** [.54, .89]	.14 [-.10, .43]	.58 [.26, .78]	.04 [-.07, .21]	− .04 [-.44, .35]
Walking episodes (number)	.16 [-.09, .44]	.64 [.39, .80]	.09 [-.13, .40]	**.71** [.39, .88]	.10 [-.10, .37]	**.70** [.45, .85]	.19 [-.10, .51]	.67 [.38, .84]	.07 [-.10, .31]	.62 [.32, .81]	.02 [-.10, .21]	.07 [-.45, .33]
Steps (number)	.20 [-.10, .50]	**.72** [.51, .85]	.05 [-.26, .43]	.34 [-.11, .68]	.09 [-.14, .37]	.41 [.05, .67]	.23 [-.10, .57]	**.73** [.48, .87]	.06 [-.15, .33]	.37 [.01, .65]	.01 [-.11, .19]	− .08 [-.47, .32]

Note. Presented are intraclass correlation coefficients (ICCs) including 95% confidence intervals of different physical activity parameters for comparisons between different combinations of consecutive days (Friday-Saturday vs. Saturday-Sunday) in subgroups (N = 53). ICCs ≥ .70 (shown in boldface) are considered acceptable for day-to-day reliability; negative ICCs indicate a reliability of zero. n = number of participants with the respective dichotomous characteristic of the subgroups; pts = points; s = seconds; m/s = meter per second; h/day = hours per day; MMSE = Mini Mental State Examination; STS = Sit-to-Stand Transitions; Active time = sum of standing and walking time; Inactive time = sum of lying and sitting time.

study sample with and without cognitive impairment, functional restrictions, and a comparable activity status (Taraldsen, Vereijken, Thingstad, Sletvold, & Helbostad, 2014). In contrast, a study exclusively in community-dwelling persons with and without cognitive impairment, but with less functional restrictions and a higher activity status compared to the present study sample, did not find mean value differences in walking time between weekdays and weekend days (Nicolai et al., 2010). Considering the contrary results of Nicolai et al. (2010) compared to those of Taraldsen et al. (2014) and of the present study, these heterogeneous results might be due to the different functional- and resulting activity levels. While higher functioning persons may be able to maintain their activity levels throughout the week, more impaired persons may reduce their activity at weekends when perceived as burdensome and daily routines such as to go shopping are reduced.

4.3. Day-to-day variability of physical activity parameters in subgroups

Since the results of the subgroup analyses revealed low day-to-day variability levels in almost all non-walking parameters in most subgroups (except for the subgroup considering activity level), regardless of the type of days, a short 2-day measurement period seems adequate.

In contrast, the walking parameters showed a recurring pattern of results with a higher day-to-day variability for different types of days and a lower day-to-day variability for similar types of days in all concomitant factors, except for lower activity level showing an equally high day-to-day variability, regardless of the type of days.

Since the day-to-day variability of some PA parameters was different between several dichotomized subgroups, the potential influence of such concomitant factors on the day-to-day variability will be discussed in detail below.

4.3.1. Gender

Our results suggest that gender does not considerably affect the day-to-day variability of various PA parameters in multi-morbid, older persons with mild-to-moderate stage dementia and therefore agree with the findings of a previous study in high-functioning and on average ten years younger community-dwelling older adults, which showed that day-to-day variability of lying time, sitting time, standing time, and walking time was not different between men and women (de la Camara et al., 2018). Contradicting results of a previous study in school children, showing a lower day-to-day variability of moderate-to-vigorous PA in boys compared to girls (Fairclough et al., 2007), suggest that in considerably different age cohorts, gender may have a different impact on day-to-day variability of PA parameters.

4.3.2. Living conditions

The present results revealed that the day-to-day variability among all PA parameters was the lowest for similar type of days in institutionalized persons. All walking parameters, when compared between weekend days, showed a low day-to-day variability sufficient for a two day assessment period in institutionalized participants, while day-to day variability of walking parameters between different types of days was comparable to other subgroups.

Observed differences and a consistently low day-to-day variability of PA parameters, especially so for similar types of days in institutionalized participants, may have been caused by the organizational framework of care facilities. Due to highly structured routines in nursing homes, the access to PA is often restricted in institutionalized persons (Benjamin, Edwards, Ploeg, & Legault, 2014). Furthermore, a reduced staffing at weekends commonly increases the need of compliance with structural workflows in nursing care facilities. This may further reduce the access to PA for nursing home residents, especially since regular group based activity programs are shut down, while daily routines such as attending meals still have a high normative impact on activity patterns (Jansen, Diegelmann, Schnabel, Wahl, & Hauer, 2017).

4.3.3. Cognitive status

Our study showed a low day-to-day variability sufficient for a two day measurement period in almost all non-walking parameters, irrespective of cognitive status and type of days, and also in walking parameters for similar type of days in persons with less cognitive impairment.

The higher day-to-day variability of all walking parameters in persons with a lower cognitive status is not in line with the outcome of a previous study reporting no difference in intra-individual variability of a single sensor-based PA parameter (activity counts) between nearly ten years younger community-dwelling elderly persons with mild Alzheimer's disease and without cognitive impairment (Watts et al., 2016).

A conceivable cause for the higher day-to-day variability of the walking parameters in cognitively more impaired persons could have been, as already assumed in the subgroup regarding living conditions, external influences. Persons with a lower cognitive status are more dependent on social support (World Health Organization, 2017), which may affect activity control and thus day-to-day variability of walking parameters. In contrast, cognitively less impaired persons are likely able to maintain a higher degree of autonomy and independently manage their activity behavior, probably resulting in a structural difference in walking parameters between weekdays and weekend days, as it has been observed in the present study.

4.3.4. Physical performance

The present study used two distinct criteria for physical performance with the five-chair-stand documenting maximal strength, and maximum gait speed documenting general performance. Contrary to our hypothesis that a high functional status may allow higher day-to-day variability of PA while low functioning persons may severely be restricted (floor effects for activity behavior), only one PA parameter (number of steps) showed a considerably different day-to-day variability between persons with a higher vs. lower functional status and only for similar type of days.

Study results are in line with a previous study in community-dwelling older persons with mild Alzheimer's disease and without cognitive impairment showing that the cardiorespiratory capacity, as a main determinant of physical performance, was not associated with the variability of PA (Watts et al., 2016). This indicates that individual physical performance levels did not affect the day-to-day variability of habitual PA in this group of multi-morbid, older persons with mild-to-moderate stage dementia.

4.3.5. Activity level

The subgroup analysis according to activity levels indicated a relevant influence of amount of activity on day-to-day variability. In contrast to other subgroup analyses, the variability of all walking parameters was rather high and not adequate for a two day assessment period, regardless of the activity level and type of days. The day-to-day variability in the low activity group stood out as the highest within all subgroup analyses and showed a high variability for all walking as well as more than half of the non-walking parameters.

Based on different study designs, sample selections, assessment strategies, and data analyses, benchmarking to other studies is limited. The present results suggest that the amount of average activity influences the day-to-day variability of walking, partly also for non-walking parameters, especially so in persons with a low activity level, and complies with the results of a previous study showing a negative correlation between average amount of PA and variability as objectively assessed by a single PA parameter (activity counts) in a mixed sample of community-dwelling, older adults with mild Alzheimer's disease and older adults without cognitive impairment (Watts et al., 2016). However, our findings contradict outcomes of another study reporting no difference in the day-to-day variability of walking and non-walking parameters in high-functioning community-dwelling older persons with a higher or lower activity level (de la Camara et al., 2018). A comparison to this study is limited, as the allocation into a higher and lower activity level in this study was based on self-report questionnaires assessing the PA of the past year and surprisingly not on the objectively measured PA as in the present study.

An explanation for the deviating results may be found in the advanced sedentariness of the study participants in the present study. The extremely high day-to-day variability of all walking parameters (in relation also of certain non-walking parameters) for similar types of days with low general activity (weekend days) in the group with a lower activity level (within a total group of sedentary, multi-morbid older persons) is striking. Our findings therefore may suggest that at very low activity levels, activity clusters may become more and more random with small absolute deviations at a very low general level leading to high relative variance, which is documented by intra-individual variability.

4.3.6. Limitation and strengths

A limitation of this study may be the short assessment period including only one weekday. However, as previous studies in older persons suggest that PA may not differ between days of the week (Hart et al., 2011; Nicolai et al., 2010) and that two days may be adequate to reliably assess the number of steps (Rowe et al., 2007), the selected measurement period was considered to be appropriate. The major strengths of our study were the inclusion of different types of days and

the subgroup analyses for different concomitant factors, as the study design allowed evaluating their impact on the day-to-day variability of various sensor-based PA parameters in multi-morbid, older persons with mild-to-moderate stage dementia.

5. Conclusion

Study results allow for the first time to define the assessment duration of various sensor-based PA parameters in a multi-morbid, older population with mild-to-moderate stage dementia, most affected by activity restrictions and challenging activity patterns that are not easy to document. Two consecutive days were adequate to reliably assess non-walking parameters, while a higher day-to-day variability of walking parameters was substantially affected by type of days and partly by concomitant factors.

Author declaration

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

We confirm that we have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, with respect to intellectual property. In so doing we confirm that we have followed the regulations of our institutions concerning intellectual property.

We further confirm that any aspect of the work covered in this manuscript that has involved human patients has been conducted with the ethical approval of all relevant bodies and that such approvals are acknowledged within the manuscript.

We understand that the Corresponding Author is the sole contact for the Editorial process (including Editorial Manager and direct communications with the office). He is responsible for communicating with the other authors about progress, submissions of revisions and final approval of proofs. We confirm that we have provided a current, correct email address which is accessible by the Corresponding Author and which has been configured to accept email from khauer@bethanien-heidelberg.de.

Declaration of Competing Interest

None.

CRediT authorship contribution statement

Bastian Abel: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing - original draft, Visualization. **Rebekka Pomiersky:** Conceptualization, Methodology, Writing - original draft. **Christian Werner:** Validation, Formal analysis, Investigation, Data curation, Writing - review & editing, Project administration. **André Lacroix:** Writing - review & editing. **Martina Schäufele:** Writing - review & editing. **Klaus Hauer:** Conceptualization, Methodology, Writing - review & editing, Visualization, Supervision, Project administration, Funding acquisition.

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