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Impact of weekdays versus weekend days on accelerometer measured physical behavior among children and adolescents: results from the MoMo study

Background

Recently, the World Health Organization (WHO) conducted a pooled data study (Guthold, Stevens, Riley, & Bull, 2020) and analyzed the worldwide trends in insufficient physical activity (PA). Using cross-sectional studies from 146 countries, they analyzed 1.6 million participants (aged 11–17 years) and found that a total of 81.0% were not sufficiently physically active worldwide in 2016, including 77.6% boys and 84.7% girls. Thus, a large proportion of adolescents do not comply with current recommendations for daily PA, which may affect their current and future health status. Due to the high level of physical inactivity, the WHO has published the action plan "More active people for a healthier world" for the period from 2018 to 2030 (World Health Organization, 2019). Among other things, it has set itself the goal of reducing physical inactivity by 15% by 2030.

Still, little is known which time periods should be targeted to effectively prevent obesity and improve PA and fitness of school-aged children. So far, most successful intervention studies for school-based PA programs have used questionnaires which are subject to recall bias and often lead to the overestimation of PA (Dobbins, Husson, DeCorby, & LaRocca, 2013; van Sluijs, McMinn, & Griffin, 2007). However, use of device-measured physical behavior (PB) is increasing for tracking school-based interventions (Mannocci et al., 2020). Device-based PB recording makes the data collected less compromised by social desirability, although it no longer captures the type of PB, but only intensity, duration, and frequency (Burchartz et al., 2021).

These intervention studies address activity behaviors on school days, but often focus on changes in moderate to vigorous PA (MVPA) only (Ajja, Wikkeling-Scott, Brazendale, Hijazi, & Abdulle, 2021; Kolle et al., 2020; Wang, 2019), thus following the WHO guidelines (Chaput et al., 2020; World Health Organization, 2010) that recommend at least 60 min MVPA per day. Time-related factors can be problematic in the school setting, such as competing demands of the education curriculum, the potential overload of teachers through additional PA breaks, or a lack of PA resources and a lack of a PA-supportive school climate. These factors can affect implementation (Naylor et al., 2015). While physical activities during school hours are more consistent, but limited in scope, weekend activities enable a much wider range of behaviors (Fairclough, Beighle, Erwin, & Ridgers, 2012; Mannocci et al., 2020). Studies showed that children get most of their MVPA during non-structured times, also at school (Bailey et al., 2012). Furthermore, large cohort studies found lower MVPA on weekends compared to weekdays or school days, whereas PA was comparable on the different weekdays (Brazendale et al., 2021; Corder et al., 2013; Fairclough, Boddy, Mack-

Data availability
The datasets generated and analyzed during the current study are not publicly available due to the strict ethical standards required by the German Federal Office for the Protection of Data with which study investigators are obliged to comply but are available from the corresponding author on reasonable request.

Table 1 Participant characteristics

Age (years)	*N*	Sex (% female)	Age M ± SD (years)			Days with WT > 8 h M ± SD			WT per day (min) M ± SD		
6–10	713	49.9	8.46	±	1.43	6.66	±	0.58	774.2	±	67.1
11–13	706	53.7	12.48	±	0.85	6.65	±	0.58	809.6	±	70.4
14–17	859	54.8	15.93	±	1.12	6.6	±	0.61	836.1	±	79.3
All participants	2278	52.9	12.52	±	3.3	6.64	±	0.59	808.5	±	77.3

N Number of participants, *M* mean, *SD* standard deviation, *WT* wear time in number of days and minutes per day, *min* minutes

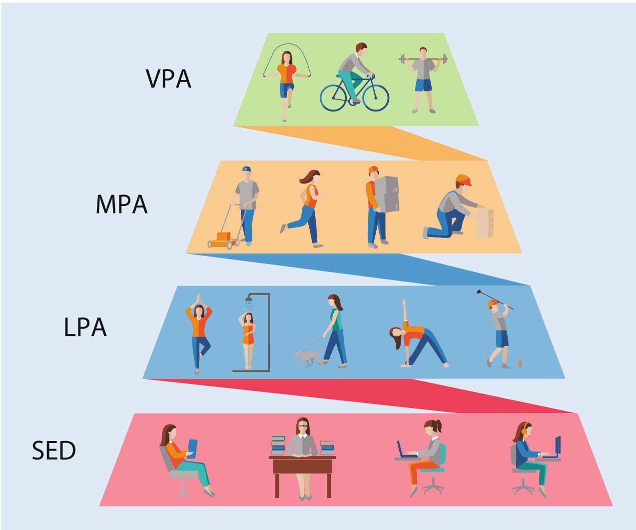

Fig. 1 ▲ MoMo—Activity pyramid that relates different physical behaviors to their intensities: *SED* Sedentary behavior, *LPA* light physical activity, *MPA* moderate physical activity, *VPA* vigorous physical activity. The pictograms represent activities in different intensities. Due to the wide age range in the MoMo study, age-unspecific representations were chosen to the extent possible (e.g., mowing the lawn symbolizes gardening, bricklaying symbolizes physical work in occupation or education, carrying packages symbolizes carrying lighter objects in contrast to weight-lifting which symbolizes lifting heavier objects)

intosh, Valencia-Peris, & Ramirez-Rico, 2015). Therefore, these studies recommend future PA interventions to target less structured days, such as weekend days, and to provide additional PA opportunities for children. However, PA intervention studies targeting children on weekends have a lower reach, are less feasible, and may reinforce social disparities, since children with a higher socioeconomic status engage in more MVPA activity types than peers with a lower socioeconomic status (Aibar et al., 2014; Love, Adams, & van Sluijs, 2019). For this reason, interventions targeting weekends only should be evaluated critically.

As mentioned earlier, the focus of PA interventions often is on changing MVPA levels according to the 2020 WHO guidelines. Regarding the time of the week, Drenowatz et al. (2016) found that longer sleep times on weekends were associated with less time spent sedentary. These extended sleep times indicate shorter awake times on weekends, which should not be ignored.

Hence, the question arises whether shorter MVPA times on the weekend are simply caused by the shorter awake phase. Or more specifically, can it be assumed that waking phase during the week is largely determined by the very structured daily school routine, while the weekend time is influenced by the changed sleeping routines? On weekends, the structure of the day is much more self-determined, but getting up later can lead to shorter waking phases. This leaves less time for activity. For example, more children do not reach 60 min of absolute MVPA on the weekend compared to schooldays as reported by Brazendale et al. (2021), Corder et al. (2013), and Fairclough et al. (2015).

More research is needed to better understand how device-based measured PB differs between weekdays/school days and weekends for children and adolescents. In addition, the complete range of PB intensity—not only MVPA, but also the proportion of other activities and sedentary intensity—should be analyzed. By capturing accelerometer data from 2014–2017, the nationwide Motorik-Modul study (MoMo) collected representative data on PB of children and adolescents in Germany. On this basis, we can now present the first detailed distribution of device-based measured PB levels in Germany. This study examines accelerometer data with respect to differences between weekdays and weekend days. In particular, the different daily patterns of intensity distributions on weekdays versus weekends as well as absolute and relative times spent in these intensities are investigated and compared.

Methods

Study design

The German Health Interview and Examination Survey for Children and Adolescents (KiGGS) is part of the Federal Health Monitoring System run by the Robert Koch Institute (RKI) and consists of regularly conducted nationwide surveys among children, adolescents, and young adults living in Germany. KiGGS Wave 2 was conducted between 2014 and 2017. The Motorik-Modul study (MoMo) is an in-depth module of KiGGS and aims to assess physical fitness, PA, as well as determinants of PA in children and adolescents (Woll, Albrecht, & Worth, 2017).

The whole study sample was drawn from the German resident population using a two-stage cluster sampling approach. Informed consent to participate in the study was obtained from all parents of the participants. Participants of earlier surveys (baseline study [2003–2006] and Wave 1 [2009–2012]) were re-invited. A detailed description of the study design and sampling procedure can be found elsewhere (Hoffmann et al., 2018; Mauz et al., 2019; Woll et al., 2017). KiGGS and MoMo provide nationally representative data of PA and sedentary behavior (SED) of children, adolescents, and young adults living in Germany. A positive vote of the ethics committee of Karlsruhe Institute of Technology (KIT) of September 23, 2014, is available for the study. The STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) statement guided the reporting of this study (Vandenbroucke et al., 2007).

Sample description

For the current analysis, cross-sectional data of participants aged 6–17 years from KiGGS and MoMo Wave 2 (2014–2017)

Abstract

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Impact of weekdays versus weekend days on accelerometer measured physical behavior among children and adolescents: results from the MoMo study

Abstract

Structured activities, in which children participate for example at school, are consistent and limited in scope. After-school or weekend activities, by contrast, involve a wider range of behaviors. Studies have shown that physical activity (PA), as measured by accelerometers, is lower on weekends compared to weekdays or school days, whereas PA does not differ between weekdays. In the present study, we examined accelerometer data of children and adolescents living in Germany for the different weekdays and weekend days. The current analysis used cross-sectional data of participants ($n=2743$) aged 6–17 years collected between 2014 and 2017. The final valid sample consisted of 2278 children and adolescents divided into three age groups (6–10 years, $n=713$; 11–13 years, $n=706$; 14–17 years, $n=859$) and two gender groups (1072 boys, 1206 girls). Physical behavior, including sedentary behavior, as well as light, moderate, vigorous PA, and wear time were analyzed. Absolute and percentage intensity distributions were evaluated daily. The average wear time was 807 min daily from Monday–Thursday with significant deviations from the mean on Friday (+38 min), Saturday (−76 min), and Sunday (−141 min). Absolute moderate to vigorous PA times were lower on weekends than during the week. However, the percentage intensity distribution remained constant over all days. Girls were less physically active and more sedentary than boys ($F_{1,2272}=38.3$; $p<0.01$) and adolescents were significantly less active than younger children ($F_{2,2272}=138.6$; $p<0.01$). Waking times increased with age ($F_{2,2272}=138.6$; $p<0.01$). Shorter awake periods limit possible active times on weekends, resulting in lower PA and sedentary behavior compared to weekdays. The percentage distributions of the different physical behavior intensity categories are similar over all weekdays and weekend days. We could not find a justification for specific weekend interventions. Instead, interventions should generally try to shift activity away from sedentary behavior towards a more active lifestyle.

Keywords

Wear time · School days · Weekend interventions · Physical exercise · Health behavior

were used ($n=2743$). Children younger than 6 years did not wear an accelerometer. A detailed dropout description can be found elsewhere (Burchartz et al., 2020). The final valid sample reaching the threshold set for wear time (WT) of 8 h on at least four weekdays and one weekend day consisted of $n=2278$ children and adolescents (Table 1). The sample was divided into three age groups (6–10 years, $n=713$; 11–13 years, $n=706$; 14–17 years, $n=859$) as well as into two gender groups (boys $n=1072$, girls $n=1206$). Gender was almost equally distributed with females representing 52.9% of the sample population.

Device-based PA data

ActiGraph GT3X+/wGT3X-BT accelerometers (Actigraph, LLC, Pensacola, FL, USA) were used to assess PA. The technical and methodological details of the present study are described elsewhere (Burchartz et al., 2020; Burchartz et al., 2021). For the present study, mean minutes of sedentary (SED), light (LPA), moderate (MPA), and vigorous PA (VPA) per weekday as well as a percentage distribution of WT were calculated (Fig. 1). The final datasets included in the analysis are of high quality with an average of 6.64 valid days (WT > 8 h) and an average WT (7 days) of 808.5 ± 77.3 min per day (more than 13 h). Subjects were instructed to take the accelerometers off only for sleeping or when in contact with water (Burchartz et al., 2020). Hence, we assumed that the wearing time was almost equivalent to the awake phase of the day. Because of the interrelationship between PA, SB, and sleep, the present manuscript uses the term "physical behavior" (PB) to refer to these three behaviors (Bussmann & van den Berg-Emons, 2013).

Statistical analysis

All statistical analyses were conducted using SPSS 28 (IBM Corporation, Armonk, NY, USA). Descriptive analyses stratified by age and gender were performed. Means (M), standard deviations (SD), and percentages were reported, as well as the corresponding inference-statistical parameters, including 95% confidence intervals (CI) for differences. Two-way analysis of variance (ANOVA) with post hoc t-test was used to analyze differences between age groups and gender. *P*-values were adjusted using the Bonferroni method for multiple comparisons. For comparison of weekdays and weekend days, Student's t-tests for paired samples were used. Effect sizes were calculated using Cohen's d (Cohen, 1988) with $|d|=0.2$ representing small effects, $|d|=0.5$ representing medium, and $|d|=0.8$ representing large effects.

Results

WT, in MoMo the assumed waking phase of the day, increased with age in our sample. Accordingly, the effect of age on WT was significant ($F_{2,2272}=138.6$; $p<0.01$) and explained 10.9% of the variance in WT. No significant difference in WT was found between gender. Leven's test for homoscedasticity was positive ($W=9.8$) due to the theory-compliant deviation of standard deviation and the high number of participants in each group.

The average WT was 806 min over all weekdays from Monday to Thursday, except for Friday. The difference to Friday was +38 min ($t=9.85$; $df=2.276$; $p<0.01$; 95% CI [−46.09, −30.78]; $|d|=0.21$). The difference to Saturday was −76 min (medium effect only for 14–17 years, $|d|=0.51$) and to Sunday was −141 min (medium effect for 6–10 years $|d|=0.67$, large effects for other age groups, $|d|=0.83/0.84$; Table 2).

The average distribution of intensities over the day was: 69% SED, 25% LPA, 3% MPA, 3% VPA (Fig. 2). There was a 1% shift from SED to LPA on Satur-

Table 2 Differences in minutes of wear time on weekdays and weekend for all participants

Age (years)		*Monday–Thursday*			*Sunday*			*Difference*				
	N	*(M ± SD)*			*(M ± SD)*			*Diff. 95% CI*		*t*	*p*	*d*
6–10	713	768.4	±	83.0	657.0	±	157.8	99.26	123.63	17.96	<0.001	**0.67**
11–13	706	804.8	±	89.1	665.5	±	168.0	126.85	151.62	22.07	<0.001	**0.83**
14–17	859	837.2	±	109.5	674.4	±	192.6	149.87	175.68	24.75	<0.001	**0.84**
All	2278	805.6	±	99.7	666.2	±	174.8	132.09	146.73	37.35	<0.001	**0.78**
Age (years)		*Friday*			*Saturday*			*Difference*				
	N	*(M ± SD)*			*(M ± SD)*			*Diff. 95% CI*		*t*	*p*	*d*
6–10	713	800.4	±	179.0	721.6	±	188.5	62.83	94.81	9.68	<0.001	0.36
11–13	706	850.3	±	193.2	738.1	±	227.9	91.87	132.60	10.82	<0.001	0.41
14–17	859	875.1	±	188.8	731.2	±	212.4	127.19	160.61	16.90	<0.001	**0.58**
All	2278	844.1	±	189.7	730.3	±	210.3	103.44	123.99	21.71	<0.001	0.46
Age (years)		*Monday–Thursday*			*Saturday*			*Difference*				
	N	*(M ± SD)*			*(M ± SD)*			*Diff. 95% CI*		*t*	*p*	*d*
6–10	713	768.4	±	83.0	721.6	±	188.5	32.97	60.62	6.64	<0.001	0.25
11–13	706	804.8	±	89.1	738.1	±	227.9	50.36	83.03	8.02	<0.001	0.30
14–17	859	837.2	±	109.5	731.2	±	212.4	92.17	119.78	15.07	<0.001	**0.51**
All	2278	805.6	±	99.7	730.3	±	210.3	66.78	83.78	17.36	<0.001	0.36

Medium and large effects are marked in **bold**
M mean, *SD* standard deviation, *diff.* difference, *95% CI* 95% confidence interval, *t* post hoc t-test, *p* Significant difference, *d* effect sizes calculated using Cohen's d

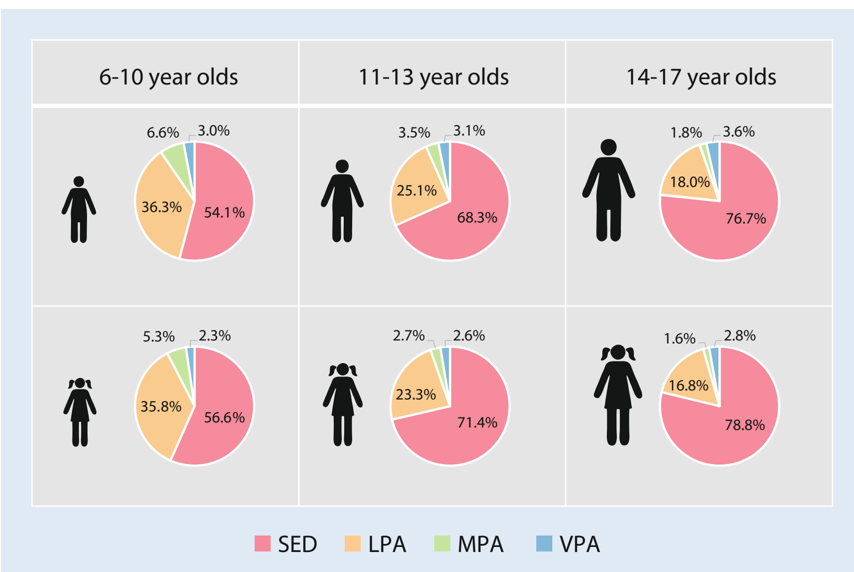

Fig. 2 ▲ Typical day (average over all 7 days) of a participant. Percentage distribution of activity intensities during the awake phase of the day for the three age groups 6–10 years (N_{male} = 357, N_{female} = 356), 11–13 years (N_{male} = 327, N_{female} = 379), and 14–17 years (N_{male} = 388, N_{female} = 471) and both genders. *SED* sedentary behavior, *LPA* light physical activity, *MPA* moderate physical activity, *VPA* vigorous physical activity

day and from VPA to SED on Sunday (**Table 3**). Absolute MVPA times were lower on weekends compared to the rest of the week (**Fig. 3**, **Tables 3 and 4**). When looking at the intensity distribution relative to the WT, however, the intensity remained constant over all days (**Fig. 3**, **Table 3**).

The youngest children (6–10 years) spent just over half of the day sedentary, whereas the oldest adolescents (14–17 years) spent almost three quarters of the day in SED (**Fig. 2** and **Table 3**).

Age explained 56.7% of the variance of SED ($F_{2,2272}$ = 1489.7; $p < 0.01$). Girls were significantly more sedentary than boys ($F_{1,2272}$ = 38.3; $p < 0.01$). The oldest age group had the longest WT and highest amount of sedentary time (**Fig. 4**). Younger children had less overall WT, but spent more time for higher-intensity activity (**Fig. 4**).

Discussion

The purpose of this study was to obtain a better understanding of how device-based PB data differ between weekdays and between school days and weekends for children and adolescents. To cover the complete range of PA intensity, not only MVPA, but also the proportion/percentage of all aspects of PB intensity as well as WT were calculated. Behavioral patterns were determined per day, gender, and age, and WT was calculated for each day of the week.

The present study revealed main differences between weekdays and weekend days. Overall, the absolute WT for the weekdays (Monday–Thursday) is 13.4 h. While the awake period on Friday is over half an hour longer (14.0 h), children and adolescents have less waking time on Sat-

Table 3 Overall mean minutes (%) of wear time (WT) in different intensities over weekdays for three age groups

Age (years)	*N*	Intensities	Monday		Tuesday		Wednesday		Thursday		Friday		Saturday		Sunday		Week	
			min (%)		min (%)		min (%)		min (%)		min (%)		min (%)		min (%)		min (%)	
6–10	713	SED	425.2	(55)	423.8	(56)	424.4	(55)	424.5	(55)	442.5	(55)	396.6	(55)	371.2	(57)	2908.1	(55)
		LPA	276.4	(36)	273.6	(36)	280.5	(36)	276.0	(36)	289.0	(36)	263.3	(36)	234.6	(36)	1893.4	(36)
		MPA	45.8	(6)	45.4	(6)	47.3	(6)	47.2	(6)	47.6	(6)	42.4	(6)	36.0	(5)	311.8	(6)
		VPA	20.8	(3)	20.5	(3)	21.2	(3)	21.0	(3)	21.3	(3)	19.3	(3)	15.2	(2)	139.3	(3)
		WT	768.2	(100)	763.3	(100)	773.4	(100)	768.7	(100)	800.4	(100)	721.6	(100)	656.9	(100)	5252.5	(100)
		MVPA	66.6	(9)	65.9	(9)	68.5	(9)	68.2	(9)	68.9	(9)	61.7	(9)	51.2	(8)	451.0	(9)
11–13	706	SED	550.7	(69)	562.9	(70)	565.8	(70)	564.5	(70)	594.8	(70)	512.6	(69)	470.3	(71)	3821.7	(70)
		LPA	194.3	(24)	192.9	(24)	194.1	(24)	191.7	(24)	203.4	(24)	184.6	(25)	161.7	(24)	1322.7	(24)
		MPA	25.2	(3)	25.9	(3)	26.0	(3)	25.7	(3)	26.4	(3)	22.1	(3)	17.9	(3)	169.2	(3)
		VPA	23.8	(3)	24.2	(3)	24.7	(3)	24.9	(3)	25.2	(3)	18.9	(3)	14.9	(2)	156.7	(3)
		WT	794.0	(100)	805.9	(100)	810.6	(100)	806.9	(100)	849.8	(100)	738.2	(100)	664.9	(100)	5470.3	(100)
		MVPA	49.0	(6)	50.1	(6)	50.7	(6)	50.6	(6)	51.6	(6)	41.1	(6)	32.8	(5)	325.9	(6)
14–17	859	SED	651.5	(78)	653.2	(78)	648.2	(77)	653.0	(78)	674.6	(77)	558.9	(76)	535.2	(79)	4374.6	(78)
		LPA	139.6	(17)	141.1	(17)	144.2	(17)	142.2	(17)	155.8	(18)	138.2	(19)	115.0	(17)	976.1	(17)
		MPA	14.2	(2)	14.8	(2)	15.3	(2)	14.7	(2)	15.9	(2)	12.9	(2)	9.7	(1)	97.5	(2)
		VPA	26.9	(3)	28.6	(3)	29.3	(4)	28.7	(3)	29.7	(3)	20.8	(3)	14.5	(2)	178.5	(3)
		WT	832.2	(100)	837.8	(100)	837.0	(100)	838.5	(100)	875.9	(100)	730.8	(100)	674.4	(100)	5626.6	(100)
		MVPA	41.1	(5)	43.5	(5)	44.6	(5)	43.3	(5)	45.5	(5)	33.8	(5)	24.2	(4)	276.0	(5)

SED Sedentary behavior, *LPA* light physical activity, *MPA* moderate physical activity, *VPA* vigorous physical activity, *min (%)* mean minutes (%) of wear time in different intensities for each weekday and the whole week

urday (12.2 h) and Sunday (11.1 h). These differences may be explained by different aspects. During structured school days, the participants get up and go to bed at similar times (Gradisar, Gardner, & Dohnt, 2011). Friday is an exception in terms of going to bed late due to the following weekend (Noland, Price, Dake, & Telljohann, 2009). Getting up late on Saturday is relativized by going late to bed (Gradisar et al., 2011; Mishra, Pandey, Minz, & Arora, 2017; Noland et al., 2009). Sunday, however, usually shows the shortest period of being awake, since after sleeping until late in the morning, the evening ends early to get enough sleep for the following school day and has similar sleep times compared to school nights (Noland et al., 2009). Based on these results, future studies should consider evaluating PB based on the sleep–wake cycle rather than on a 24 h basis or on the external construct of time of day. In this case, the night from Friday to Saturday may already be counted as a weekend day and the night from Sunday to Monday as a school-related day. This could have further positive implications in view of the current 24 h PB debate. One option would be to determine threshold parameters for the separation of sleep and waking phases, which would then no longer require the use of fixed 24 h evaluation windows, but would allow the actual influence of sleep and waking times on PB to be investigated. For example, it would be possible to make even more realistic assumptions on how sleep behavior affects psychological factors such as mood and other parts of PB. Furthermore, it could be examined how much influence the day before has in contrast to the day following the sleep phase. Questions that could be addressed in this connection include: Is the night after a day off more attributable to the following school day or to the day off/weekend? What is the influence of the night from Friday to Saturday or before a day off, which starts later but also lasts longer, compared to that of a night between two school days or workdays? This would allow considering different sleeping patterns. In contrast to fixed daily analyses that use periods from midnight to midnight, the actual daily sleep phases

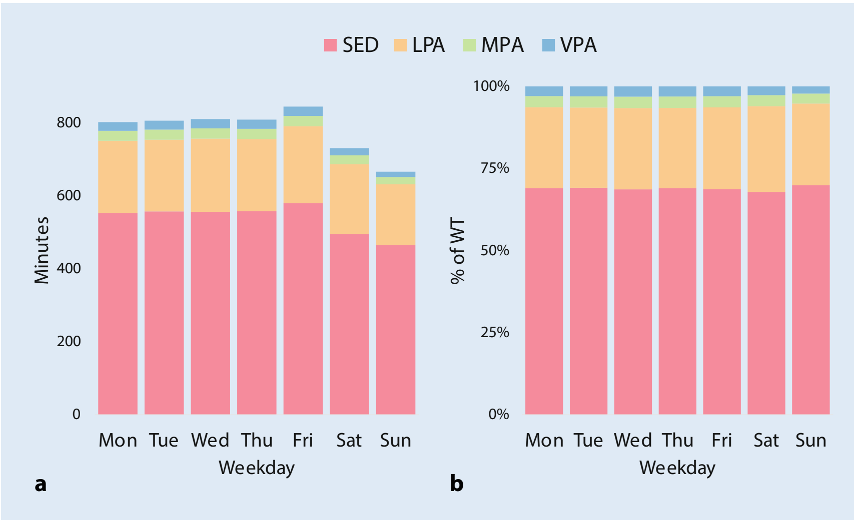

Fig. 3 ▲ Overall (*N* = 2278) mean minutes in different intensities for all weekdays. *SED* Sedentary behavior, *LPA* light physical activity, *MPA* moderate physical activity, *VPA* vigorous physical activity, **a** *Minutes of wear time* means the absolute minutes of wear time among intensity classes on weekdays, **b** *% of wear time* (*WT*) is the percentage distribution of wear time among intensity classes

could then be taken into account. In this way, changes in sleep patterns, such as different bedtimes on different weekdays, could be considered.

However, this would require data for the complete 24 h PB cycle over one or more weeks and cannot be done with the data underlying this study.

As a second result, this study showed similar day patterns for all age groups in terms of intensity distribution. The pattern of the waking phase of the day in the form of WT is also consistent for all groups. The total minutes of WT per day increased with age, which is in line with the observed decrease in sleep hours with increasing age (Chaput, Dutil, & Sampasa-Kanyinga, 2018). With less sleep during the night, waking time during the day increases.

The distribution of activity intensity over a day is in line with previous studies. A 25% increase in SED correlated with age coincided with changes in children's school curricular activities (Crane, Naylor, & Temple, 2018; Troiano et al., 2008; Williams, Zimmerman, & Bell, 2013). Interestingly, the percentage of VPA remains consistent across age groups at about 3%, with girls consistently engaging in less VPA than boys. This must be emphasized in the context of the longer waking time of older subjects, as this increases the absolute minutes of VPA by 5 min (**Fig. 3**, **Table 3**). These results are in line with a cross-sectional study by Steele et al. (2010) who found no difference in percentage time of VPA for weekdays and weekends in accelerometer measurements for children aged 9–10 years. The same was found by Drenowatz et al. (2016) for young adults and by Aibar et al. (2014) for Spanish and French children. This positive trend in the relatively small increase in absolute VPA is also compensated by a reduction from 6% to below < 2% for MPA and a decrease of LPA from 36% to 17% when comparing the younger participants (6–10 years) with the older ones (14–17 years).

No significant differences in WT were found between boys and girls. However, a significantly higher proportion of SED and a lower proportion of LPA, MPA, and VPA in the daily average was observed for girls (**Fig. 1**, **Table 3**), with this gender gap being repeatedly reported by many studies (Berglind & Tynelius, 2017; Guthold, Stevens, Riley, & Bull, 2018, 2020; Padmapriya et al., 2021; Steele et al., 2010).

Considering our study's results in the context of previous studies, most studies showed longer MVPA time during the week compared to the weekend. Brazendale et al. (2021) found similar results in a study using pooled accelerometer data from the ICAD (International Children's Accelerometry Database) project, which revealed that children accumulated approximately 10 min more MVPA on school days (as much as 17 min more in European children) compared to weekend days. Similar results were reported by Corder et al. (2013) and Steele et al. (2010). Some studies found also less time spent in SED on weekend days compared to weekdays (Corder et al., 2013; Frago-Calvo, Aibar, Ibor, Generelo, & Zaragoza, 2018) and concluded that this may be explained by a lack of typically structured SED associated with school lessons.

Until now, we are not aware of any PA study that considers the significantly lower awake periods on weekends. The present results suggest that the percentage intensity distribution of SED, LPA, MPA, and VPA on the weekend is similar to that during the week, including Friday, despite the lower WT (**Fig. 2**). As can be seen in detail in **Table 3**, there is only a small 1% shift from SED to LPA on Saturday and a 1% reduction in VPA on Sunday that can be attributed to the SED increase compared to the weekdays. Hence, lower MVPA and SED times on the weekend cannot be attributed to a fundamental change in PA behavior. On the contrary, the PB patterns observed during the week also prevailed on the weekend. Since the shorter waking phase on the weekend indicates that less time is available overall, this also results in less time spent for the different PB intensities. With this in mind, we were unable to find any justification for specific weekend interventions based on PA distribution. Instead, we recommend interventions to generally shift activity behaviors from SED towards a more active lifestyle (more LPA, MPA, and VPA).

Because of the distinct differences between weekday and weekend activity levels, previous studies recommended to collect data on both weekdays and weekend days (Trost, McIver, & Pate, 2005; Vanhelst, Fardy, Duhamel, & Béghin, 2014). However, some authors disagreed with the inclusion of weekend data in PA analysis (Wolff-Hughes, McClain, Dodd, Berrigan, & Troiano, 2016). Although the inclusion of weekend data can introduce bias into PA estimates, most studies typically use measurement periods of

Table 4 Minutes of wear time on weekdays and weekend days

Age (years)			*Monday-Thursday*			*Friday*			*Difference*				
		N	*(M ± SD)*			*(M ± SD)*			*Diff. 95% CI*		*t*	*p*	*d*
6–10	m	357	771.6	±	84.1	807.9	±	186.7	−55.16	−17.46	−3.79	< 0.01	−0.20
	f	356	765.2	±	81.9	792.9	±	170.8	−45.28	−10.18	−3.11	< 0.01	−0.17
	Ø	713	768.4	±	83.0	800.4	±	179.0	−44.88	−19.18	−4.89	< 0.01	−0.18
11–13	m	327	798.7	±	91.0	843.1	±	202.6	−66.01	−22.82	−4.05	< 0.01	−0.22
	f	379	810.1	±	87.2	856.6	±	184.7	−64.65	−28.37	−5.04	< 0.01	−0.26
	Ø	706	804.8	±	89.1	850.3	±	193.2	−59.46	−31.61	−6.42	< 0.01	−0.24
14–17	m	388	830.3	±	120.3	874.9	±	189.9	−64.29	−24.96	−4.46	< 0.01	−0.23
	f	471	842.9	±	99.5	875.3	±	188.2	−49.66	−15.13	−3.69	< 0.01	−0.17
	Ø	859	837.2	±	109.5	875.1	±	188.8	−50.88	−24.96	−5.74	< 0.01	−0.20
All	m	1072	801.1	±	103.5	842.9	±	194.7	−53.31	−30.27	−7.12	< 0.01	−0.22
	f	1206	809.6	±	96.1	845.1	±	185.2	−45.67	−25.24	−6.81	< 0.01	−0.20
	Ø	2278	805.6	±	99.7	844.1	±	189.7	−46.09	−30.78	−9.85	< 0.01	−0.21
Age (years)			*Saturday*			*Sunday*			*Difference*				
		N	*(M ± SD)*			*(M ± SD)*			*Diff. 95% CI*		*t*	*p*	*d*
6–10	m	357	728.2	±	194.1	659.7	±	166.9	43.89	93.09	5.48	< 0.01	0.29
	f	356	715.0	±	182.8	654.2	±	148.4	38.43	83.18	5.35	< 0.01	0.28
	Ø	713	721.6	±	188.5	657.0	±	157.8	48.06	81.24	7.65	< 0.01	0.29
11–13	m	327	740.0	±	230.4	655.6	±	191.5	54.45	114.32	5.55	< 0.01	0.31
	f	379	736.5	±	226.0	674.2	±	144.3	37.04	87.60	4.85	< 0.01	0.25
	Ø	706	738.1	±	227.9	665.5	±	168.0	53.17	91.91	7.35	< 0.01	0.28
14–17	m	388	728.0	±	223.0	669.3	±	190.3	32.61	84.77	4.42	< 0.01	0.23
	f	471	733.9	±	203.4	678.7	±	194.5	32.75	77.73	4.83	< 0.01	0.22
	Ø	859	731.2	±	212.4	674.4	±	192.6	39.78	73.82	6.55	< 0.01	0.22
All	m	1072	731.7	±	216.0	661.9	±	183.1	54.35	85.23	8.87	< 0.01	0.27
	f	1206	729.1	±	205.2	670.0	±	167.0	45.59	72.63	8.58	< 0.01	0.25
	Ø	2278	730.3	±	210.3	666.2	±	174.8	53.94	74.33	12.34	< 0.01	0.26

m male, ***f*** female, ***Ø*** mean of males and females, ***M*** mean, ***SD*** standard deviation, ***diff***. difference, ***95% CI*** 95% confidence interval, ***t*** post hoc t-test, ***p*** Significant difference, ***d*** effect sizes calculated using Cohen's d

four out of seven valid days, including at least one weekend day, to calculate PA (Skender et al., 2016). Due to the results of the present study that show that durations of the waking phases differ on Saturday and Sunday, we assume that PA evaluation may be influenced by the type of weekend day included in the analysis. We suggest that evaluations should continue to include weekend days. Due to the high proportion of valid days (m = 6.64) in the MoMo study, we consider the presented data as robust. However, studies with a small sample should consider the potential influence of different weekend days in their analysis (if quality assessment specifications like 4 + 1 are used: four valid weekdays and one [random] weekend day). In addition to absolute minutes, relative proportions of MVPA should be reported in future studies.

The present study is limited due to its cross-sectional nature and we do not intend to infer causality. The main goal of MoMo is to track and report PA and fitness of children and adolescents in a nationwide sample, and significant effort was put into collecting representative data from 167 sample points all over the country.

In the light of the recent development to assess 24 h PB, however, the present study is subject to the restriction that the accelerometer measured PA during one specific week and during waking hours only. Keeping an additional comprehensive and elaborate diary was avoided during the week by wearing an accelerometer. Study participants carried the accelerometer following the completion of the already very time-consuming fitness test and surveys on activity and health. A WT of 24 h could solve this problem in future studies. Although we attempted to solve most of the methodological problems in our accelerometer-measured PA, difficulties remained, such as calibration for a wide age range and the occurrence of non-wear times during sports competitions.

This study's advantages are the large and nationwide sample ($N = 2278$) and the recording of PA of each participant by a PA questionnaire as well as by accelerometry. We collected the sample at 167 locations across Germany throughout the whole year to account for seasonal effects. To our knowledge, this study was one of the first to take a look at the individual waking phases of each day in a week and combine it with an analysis of absolute as well as relative PA intensity data measured by accelerometers.

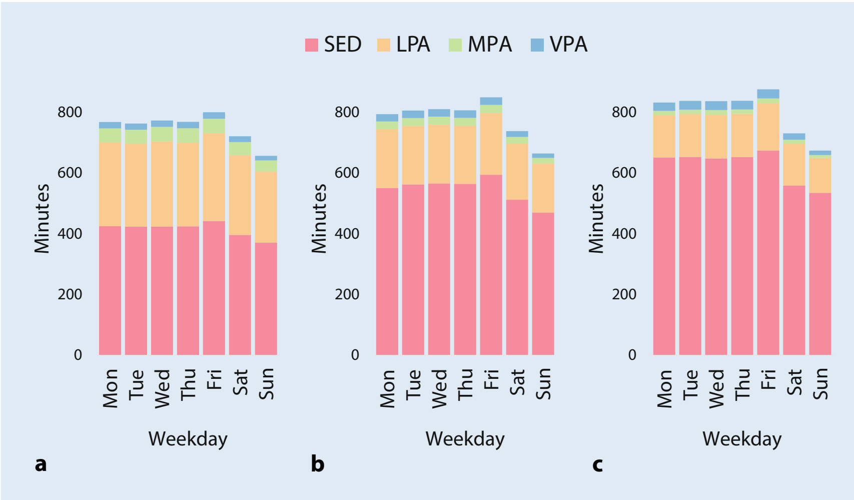

Fig. 4 ▲ Overall mean minutes in different intensities over weekdays for three age groups. **a** Absolute minutes among intensity classes on weekdays for 6–10 year olds (N_{male} = 357, N_{female} = 356), **b** 11–13 year olds (N_{male} = 327, N_{female} = 379) and **c** 14–17 year olds (N_{male} = 388, N_{female} = 471). *SED* Sedentary behavior, *LPA* light physical activity, *MPA* moderate physical activity, *VPA* vigorous physical activity

Apart from PA, many other parameters were collected in MoMo. This results in a multitude of further evaluation options. Closer examination of the data in MoMo (e.g. fitness levels, sports disciplines, socioeconomic status, migration status) will give a more detailed answer as to the reasons behind the differences regarding age and gender.

Conclusion

This study was the first to provide detailed insights into device-based PA behavior on a national level in Germany. The results regarding the PA patterns on weekdays and weekends allow the conclusion to be drawn that participants' WT increases with age because the waking phase during the day increases. However, despite the longer waking periods on Friday and Saturday (in terms of absolute minutes), the percentage distribution of time spent in the different activity intensities is similar on all weekdays and weekend days. Since shorter waking periods limit the possible absolute active time on weekends, PA and SED times are lower on the weekend compared to weekdays. The visualization of PA on a typical day for an average MoMo participant may help researchers compare their data. We could not find any justification for specific weekend interventions from PA level distributions alone. Instead, we think that interventions should generally try to shift activity behavior from SED towards a more active lifestyle. We recommend that low-threshold sports, play, and exercise facilities for children and adolescents should be increased and promoted on the municipal level. Here, public open spaces and exercise areas (e.g., paths, squares, courtyards, green spaces, forests, playgrounds, football fields, and skate parks) should be created to support a generally more active lifestyle. Joint efforts to ensure physical activity and sports offerings in schools, clubs, and leisure time are necessary on the federal, state, and local levels and should be funded extensively within a federal pact to promote PA (Woll, Scharenberg, Klos, Opper, & Niessner, 2021).

In the present study, we provided daily patterns for intensity distributions of PA levels. We suggest that PA analysis from wakeup to wakeup may not be a fixed 24 h PB cycle. Due to sleeping patterns, for example, there is more time for being active on Friday compared to Saturday, which is why comparability of these two days is limited. In the future, this should be considered when interventions are made and evaluated. Future studies of PB should consider using the sleep–wake cycle rather than the 24 h basis.

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Declarations

Conflict of interest. A. Burchartz, D. Oriwol, S. Kolb, S.C.E. Schmidt, B. von Haaren-Mack, C. Niessner and A. Woll declare that they have no competing interests.

All procedures performed in studies involving human participants or on human tissue were in accordance with the ethical standards of the institutional and/or national research committee and with the 1975 Helsinki declaration and its later amendments or comparable ethical standards. For MoMo, ethics approval was obtained from the Charité Universitätsmedizin Berlin ethics committee, the University of Konstanz, and the ethics committee of Karlsruhe Institute of Technology. The Federal Commissioner for Data Protection and Freedom of Information was informed about the study and approved it. Informed consent was obtained from all individual participants included in the study.

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