

Title: Quantification of walking-based physical activity and sedentary time in individuals with Rett syndrome

Running title: Physical activity in Rett syndrome

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Word count: 3174/3000

This is the peer reviewed version of the following article: Downs, J. and Leonard, H. and Wong, K. and Newton, N. and Hill, K. 2017. Quantification of walking-based physical activity and sedentary time in individuals with Rett syndrome. *Developmental Medicine and Child Neurology*. 59 (6): pp. 605-611, which has been published in final form at <http://doi.org/10.1111/dmcn.13398>. This article may be used for non-commercial purposes in accordance with Wiley Terms and Conditions for Self-Archiving at <http://olabout.wiley.com/WileyCDA/Section/id-828039.html#terms>

ABSTRACT

Aims: In individuals with Rett syndrome and capacity to walk, to quantify walking-based activity and sedentary time and analyse the influences of age, walking ability, scoliosis and the severity of epilepsy.

Method: Sixty-four participants with a mean age of 17 years 7 months (SD 9 years) were recruited from the Australian Rett Syndrome Database for this cross sectional study. Each participant wore a StepWatch Activity Monitor for at least four days. Linear regression models were used to assess relationships between daily step count and the proportion of waking hours spent in sedentary time with the covariates of age group, walking ability, presence of scoliosis and frequency of seizures.

Results: On average 62% (SD 19%) of waking hours were sedentary and 20% (SD 8%) was at cadences ≤ 20 steps in a minute. The median (IQR) daily steps was 5,093 (2,026 to 8,602). Compared with girls younger than 13 years and accounting for the effects of covariates, adults took fewer steps and both teenagers and adults had more sedentary time.

Interpretation: Teenagers and adults led the least active lives and would appear to be in particular need of interventions which would aim to optimise slow walking-based physical activity and reduce sedentary time.

Key words: Rett syndrome, walking-based physical activity, sedentary behaviour, disability, activity monitoring

What this paper adds

- Females with Rett syndrome were sedentary for most waking hours.
- Walking-based physical activity was mostly undertaken at slow cadences.
- Both teenagers and adults had more sedentary time than children.
- Reduced activity with age could relate to impairments and/or opportunity.

Rett syndrome is a genetically caused neurodevelopmental disorder that mainly affects females. It is associated with loss of hand and/or communication skills, the development of hand stereotypies and abnormal gait in early childhood.¹ Gross motor function continues to be affected over the life span. Whilst the majority of females are able to sit, slightly less than half are able to walk independently.² Comorbidities, in particular, scoliosis and epilepsy develop in approximately three quarters of individuals before adulthood^{3,4} although the median age of onset of epilepsy is four years⁵ compared with a later median age of onset of 11 years for scoliosis.³ Movement limitations coupled with comorbidities place individuals with Rett syndrome at increased risk of reduced physical activity and greater sedentary time.

Regular participation in physical activity has been associated with numerous health benefits in relation to energy balance, bone health, physical fitness and psychological well-being.⁶ Nevertheless, participation in walking-based physical activity is problematic for those with a neurological condition. Using accelerometer data, children with cerebral palsy⁷ and adults with Down syndrome⁸ have been shown to engage in substantially lower levels of walking-based physical activity compared with the general population. The difficulties associated with participating in regular walking-based physical activity could reflect neurological impairments such as poorer motor skills and coordination, difficulties with cognition and motivation, and/or limited opportunities for activity.

It is therefore important to understand how waking hours are spent in those with a neurological condition. Data are emerging to show that children and adolescents with cerebral palsy⁷ accumulate large amounts of sedentary time, defined as behaviours undertaken in lying or sitting which require low levels of energy expenditure.⁹ The amount of sedentary behaviour in those with Rett syndrome could also be high.

We recently validated the StepWatch Activity Monitor (StepWatch) as an accurate measure of step counts in Rett syndrome.¹⁰ Using the StepWatch, the aim of the current study was to explore and analyse the proportion of waking hours spent in walking-based physical activity, across a range of cadences, and the proportion of waking hours spent in sedentary time in those with Rett syndrome. We also examined the influences of age, walking ability, scoliosis and seizure frequency on the average total daily step count and sedentary time in this population.

METHOD

Participants

The population-based and longitudinal Australian Rett Syndrome Database was the data source for this study.^{3,11} Following registration of their child with the database, a questionnaire is administered to the family and a diagnosis of Rett syndrome is confirmed by the presence of a pathogenic *MECP2* mutation or by fulfilment of the most recent diagnostic criteria.¹ Seven follow-up questionnaires have been administered between 1996 and 2012 to families and carers of registered cases.³ During 2012, families whose daughter could walk independently or with assistance as indicated in the database were invited to participate in this exploratory study. Longitudinal questionnaire data were interrogated to identify whether scoliosis or epilepsy had been diagnosed or not, and seizure frequency was extracted from the 2012 follow-up questionnaire. The covariates for analyses included: (i) age (younger than 13 years, 13 to 18 years or 19 years and older), (ii) walking ability (able to walk independently or needing assistance to walk) and, (iii) comorbidities (scoliosis - having scoliosis or not; frequency of seizures - no seizures or no seizures in the last 2 years, less than monthly or monthly, weekly or daily). The Human Research Ethics Committees at Curtin University

(HR 139/2011) and Princess Margaret Hospital for Children (1909EP) approved this study, and participation was based on informed consent.

Measurement of walking-based physical activity and sedentary time

Participating families were provided with a StepWatch (Modus Health LLC, Washington, DC) and an instruction sheet for its wear. These were either posted (with a reply-paid envelope for return) or provided in person (for families who lived locally). The StepWatch is a small monitor that attaches to the right ankle using a Velcro strap and as per our previous study,¹⁰ was configured for the height of each participant and settings were standardised for a gentle and slow gait that rarely varied in pace and was without short quick steps. Each participant wore the StepWatch in their usual environment and during waking hours for a seven-day period, with the exception of bathing or swimming. The primary caregiver completed a seven-day diary to track waking hours, the time the StepWatch was applied and removed, and reasons for not wearing the device during the day.

StepWatch data management

StepWatch data were exported to a database and the number of steps for each minute doubled as the StepWatch records steps taken by the right leg only. Thereafter, both diary and step count data were interrogated. In order to be included in these analyses, each participant needed to contribute a minimum of four days of data including at least one weekend day,¹² with each day meeting the following criteria:

1. A minimum of 100 steps were recorded (days with very low steps counts were excluded as it was unlikely the StepWatch was worn correctly, if at all).
2. A minimum of nine hours of wear time was recorded.¹³ For each day, wear time was defined as the difference in time between when the first and last steps were taken. These times were extracted from the StepWatch data in the database and verified using diary data.
3. According to the diary data, there was no indication that the StepWatch had been removed for longer than 30 minute periods (approximate time for showering) without the carer clearly documenting the start and end time of non-wear periods. In instances where the carer had documented in the diary that the StepWatch had been removed during the day (e.g. for swimming) and had also recorded the times, these periods of non-wear time were excluded from analyses. However, data over the remainder of these days were eligible for inclusion in the analyses, providing a minimum of 100 steps had been recorded and at least nine hours of wear time data were available.

Where participants contributed four valid days, additional days that met these criteria up to seven days were also included in the analyses. For each participant and across each day, each minute of data was grouped into the following categories; (i) 0 steps in a minute (i.e. sedentary time), (ii) 1 to 19 steps in a minute, (iii) 20 to 39 steps in a minute, (iv) 40 to 59 steps in a minute, (v) 60 to 79 steps in a minute, (vi) 80 to 99 steps in a minute, (vii) 100 to 119 steps in a minute and, (viii) 120 or more steps in a minute. These categories, albeit arbitrary, have been used previously to explore differences in walking-based physical activity in the general population.¹⁴ To mitigate the influence that differences in daily wear time may have had on the results, time in each category was expressed as a percentage of total wear time for that day. Thereafter, percentage time spent in each of these categories was averaged between days.

Statistical analyses

Chi squared tests of association were used to compare the distributions of covariates for (i) those registered with the database with (eligible) and without (not eligible) walking ability, and (ii) if eligible, those who participated and those who did not. The percentages of awake time in each of the steps/minute categories were plotted as boxplots for each of the independent variable categories. The distribution of average daily step count was positively skewed and therefore this variable was log transformed in the linear regression model to assess relationships with the covariates of age group, walking ability, presence of scoliosis and the number of antiepileptic drugs. The resulting coefficient was exponentiated to represent the ratio of the expected geometric mean for each category in relation to the baseline category. A linear regression model was also used to assess relationships between the proportion of waking hours spent in sedentary time and the covariates. The estimated coefficients and 95% confidence intervals were reported for each model and statistical significance was defined as $p < 0.05$. All statistical analyses were conducted using STATA version 14 (StataCorp LP, College Station, TX).

RESULTS

At the end of 2012, the Australian Rett Syndrome Database was in contact with 251 families/carers who had a daughter with confirmed Rett syndrome who was alive. Of these, 94 (37.4%) were unable to walk and 157 (62.5%) were eligible to participate in the study as they walked either independently or with assistance. The distributions of mutation, age group, and the presence of scoliosis and epilepsy for those with and without walking skills are shown in Table 1. Compared to those with walking skills, higher proportions of those who were unable to walk had an early truncation or p.Arg168* mutation and smaller proportions had a C-terminal deletion, p.133Cys, p.Arg306Cys or p.Arg294* mutation ($p = 0.002$). Proportions of individuals were similar across the age groups ($p = 0.311$) but compared to those with walking skills, higher proportions who were unable to walk had been diagnosed with scoliosis ($p < 0.001$) or epilepsy ($p = 0.001$).

Of those who were eligible for the study ($n = 157$), approximately three quarters (76.6%) walked independently and one quarter walked with assistance (Table 1). The proportion of those who walked independently versus with assistance was similar irrespective of whether or not they participated in the study ($p = 0.436$). The common mutation groups were similarly represented in those who participated and those who did not ($p = 0.263$) and no female with a p.Arg255* mutation participated. Compared to those who were not in the study, more girls were younger than 13 years (39.1% vs 22.6%; $p = 0.083$) and a smaller proportion had scoliosis (50.0% vs 63.4%; $p = 0.094$) but these differences did not reach statistical significance. The proportion of individuals who had been diagnosed with epilepsy (70.1% vs 78.4%; $p = 0.467$) and the distribution of seizure frequency was broadly similar ($p = 0.962$) (Table 1).

Eighty-eight families (56%) were recruited and 64 participants [mean age 17 years 7 months SD 9 years, range 3 years 6 months to 38 years] provided adequate StepWatch data to be included in analyses. These participants contributed a median of 5 (range 4 to 7) days of StepWatch data over a median of 11.3 (range 9.0 to 15.7) waking hours. An average of 62% (SD 19%) of waking hours was spent in sedentary time equivalent to 7.2 (SD 2.5) hours. An average of 20% (SD 8%) of waking hours was spent in light intensity walking, defined as cadences ranging from 1 to 19 steps in a minute, and equivalent to 2.2 (SD 1.0) hours per day. The proportion of waking hours walking at cadences ≥ 20 steps in a minute was small and progressively decreased as cadence increased. Figures 1 and 2 present data with participants grouped by age, walking ability, presence of scoliosis and severity of epilepsy. Data consistently demonstrated that the majority of waking hours were spent in sedentary

time and that few participants walked at fast cadences but only for very limited periods of time.

The median average daily steps was 5,093 (IQR 2,026 to 8,602). The relationships between daily steps and the covariates in the univariate and multivariate models are shown in Table 2. Taking into account the effects of walking ability, scoliosis and seizure frequency, females aged ≥ 19 years took 61.8% fewer steps than girls younger than 13 years (coefficient 0.382; 95% confidence interval [CI] 0.260, 0.562). Taking into account the effects of age, scoliosis and seizure frequency, those who walked independently took on average twice the number of steps each day compared to those who needed assistance (coefficient 2.111; 95% CI 1.419, 3.143). The presence of scoliosis was not associated with daily step count when the model accounted for the effects of other covariates. Compared to those who did not have seizures, those with weekly or daily seizures took 36.7% fewer steps (coefficient 0.633; 95% CI 0.406, 0.986; $p=0.044$) (Table 2).

Relationships between walking ability, the presence of scoliosis, seizure frequency and percentage of sedentary time broadly reflected relationships with daily steps but in the opposite direction (Table 2). Notably in the multivariate model, both teenage girls and adults had greater sedentary time than girls younger than 13 years (13 to 18 years: coefficient 14.1, 95% CI 3.6, 24.7 and ≥ 19 years: coefficient 22.6, 95% CI 14.6, 30.5), taking into account the effects of walking status, scoliosis and seizure frequency (Table 2).

DISCUSSION

Using a validated activity monitor, we quantified walking-based physical activity and sedentary time in girls and women with Rett syndrome. Even with the capability of walking, children and adults were sedentary for on average two-thirds of their waking hours, greater than observed in typically developing children (approximately 20%) and those with cerebral palsy (approximately 25%),¹³ and more than in adults in the general population (approximately 56%).¹⁵ Those at greatest risk of high levels of sedentary time and low levels of walking-based physical activity were older than 19 years, required assistance to walk and experienced frequent seizures.

Our data showed a clear effect of advancing age on activity. That is, adults engaged in less walking-based physical activity compared with children younger than 13 years and both teenagers and adults were more sedentary than children. Neurological impairments such as dystonia, rigidity and bradykinesia may develop with age^{16,17} making movement difficult. Increased general clinical severity has been reported with age in Rett syndrome, even in those with milder mutation types such as the p.Arg133Cys, p.Arg306Cys and p.Arg294*¹⁸ despite their usually stronger gross motor skills.² The decline in activity could have been associated with comorbidities such as progression of scoliosis and the toll of ongoing epilepsy although these had lesser influence in the multivariate models. In addition to disease impairments, puberty and environment factors such as reduced expectation and support for physical activities could also have contributed. Teenage girls in the general population are particularly vulnerable to reduced physical activity and increased sedentary behaviour¹⁹ and our observations are in parallel with these wider trends. Either way, high sedentary time with prolonged mechanical unloading of the skeletal muscles leads to muscle atrophy and weakness²⁰ potentially contributing to reduced walking-based activity. We acknowledge that this is a cross sectional study but sedentary time increased in the teenage years whereas there was only a small reduction in activity and this preceded the marked deterioration in daily step

count observed in adulthood. Further attention to changing neurology, therapy goals and opportunities for activity of the teenagers would seem justified.

Our finding that independent walking enabled greater walking-based physical activity and less sedentary time is not surprising. Performing transition movements such as sit to stand are believed to be influenced by dyspraxia and are typically difficult in Rett syndrome² although once assisted to the standing position, those who can walk will usually take steps.²¹ We have previously observed that, compared to those unable to walk, maintenance of walking skills is associated with less marked progression of scoliosis.³ Extending our understanding for those with walking skills, scoliosis had little relationship with the amount of activity. However, more frequent seizures had a detrimental effect on activity, possibly in relation to reduced energy levels following seizures or side effects from antiepileptic medications such as lethargy, sleepiness and poor balance.²²

In youth with developmental disability, physical activity has been associated with improved motor skills and fitness²³ and possibly contributes to quality of life in Rett syndrome.²⁴ The average daily step count in our sample was 5,093 steps, markedly less than the minimum of 11,000 to 12,000 steps generally recommended for girls²⁵ and 10,000 steps for adults.²⁶ It is similar to the cut-point of 5,000 steps believed to indicate a sedentary lifestyle in the general population²⁷ and consistent with earlier work in other neurodevelopmental disorders such as cerebral palsy.⁷ Irrespective of walking ability, the majority of walking-based activity in our study was undertaken at very slow cadences. The neurological impairments in Rett syndrome likely preclude moderate to vigorous walking-based physical activity even in those who can walk independently. Interventions that aim to increase walking-based physical activity for those with walking skills in Rett syndrome are an important area for future studies and may be guided by the measurement of uptime using our recently validated modified Bouchard activity record.²¹ As for other neurological conditions,²⁸ our current data suggest that slow walking-based physical activity is the most viable target in this population.

We collected data from a substantial sample of individuals with the rare disorder Rett syndrome but we acknowledge some limitations. Additional data describing seizure type and duration in addition to seizure frequency would be important to more clearly understand the relationship between seizure severity and physical activity. We observed that the majority of activity was in the slowest cadence band and was therefore likely light. However, there is no literature investigating the intensity of physical activity associated with the different cadence bands in Rett syndrome and we were unable to comment on what activity was moderate or vigorous in intensity. Other limitations relate to the possibility that some recorded activity related to movements other than walking such as involuntary movements. We defined sedentary time by grouping any one-minute epoch with a step-count of zero and we acknowledge that this was a conservative cut-point and we have likely under-estimated sedentary time.

This study has demonstrated that individuals with Rett syndrome who are able to walk spend the majority of their waking hours in sedentary time and little time in walking-based physical activity. Almost all walking-based physical activity was undertaken at slow cadences. Teenagers and adults led the least active lives and would appear to be in particular need of further assessment in relation to their physical capability and modifiable environmental factors with the goal of increasing physical activity. Our findings can guide multidisciplinary initiatives in identifying supports for those with Rett syndrome to both optimise slow walking-based physical activity and reduce sedentary time.

ACKNOWLEDGMENTS

The authors would like to thank those families who participate in the Australian Rett Syndrome Study and gave their time to participate in this study. We extend our gratitude to the Australian Paediatric Surveillance Unit (APSU) and the Rett Syndrome Association of Australia for their ongoing support in case ascertainment. We also thank the organisations that have provided funding for the Australian Rett Syndrome Study. The Australian Rett Syndrome Study was previously supported by the National Institutes of Health Grant 5R01HD043100-05 and National Health and Medical Research Council project grants #303189 and #1004384. This study was funded by Rettsyndrome.org through the HeART grant mechanism. The funders of this research have had no roles in the study design, data collection, data analysis, manuscript preparation and / or publication decisions.

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FIGURE LEGENDS

Figure 1: Box plots of waking time spent in sedentary and in the different cadence bands for participants according to walking ability (independent and with assistance) and age group (younger than 13 years, 13 to 18 years and 19 years and older). The boxes show, from bottom to top, the 25th percentile, median and 75th percentile values and the error bars indicate the lower and upper adjacent values. The upper adjacent value is defined as the largest data point less than or equal to 75th percentile + 1.5 IQR and the lower adjacent value is defined as the smallest data point more than or equal to 25th percentile - 1.5 IQR. The outside values, which are data points more extreme than the upper and lower adjacent values, are individually plotted.

Figure 2: Box plots of waking time spent in sedentary and in the different cadence bands for participants according to the presence of scoliosis (no scoliosis, with scoliosis) and epilepsy (no seizures or none in the last 2 years, less than monthly or monthly, weekly or daily). See description of box plots in caption of Figure 1.

Figure 1

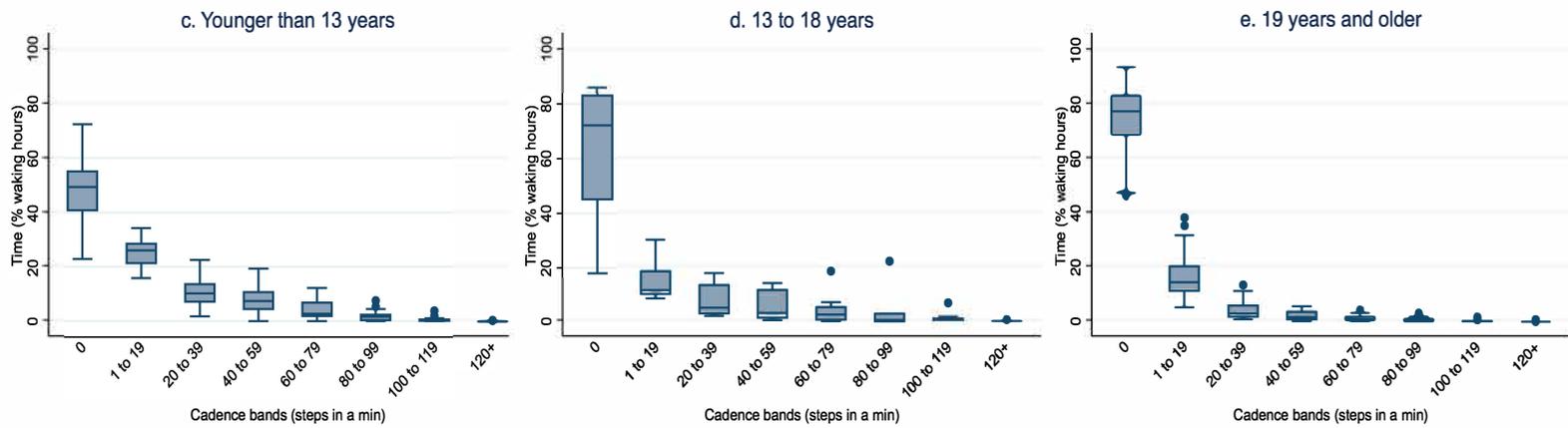
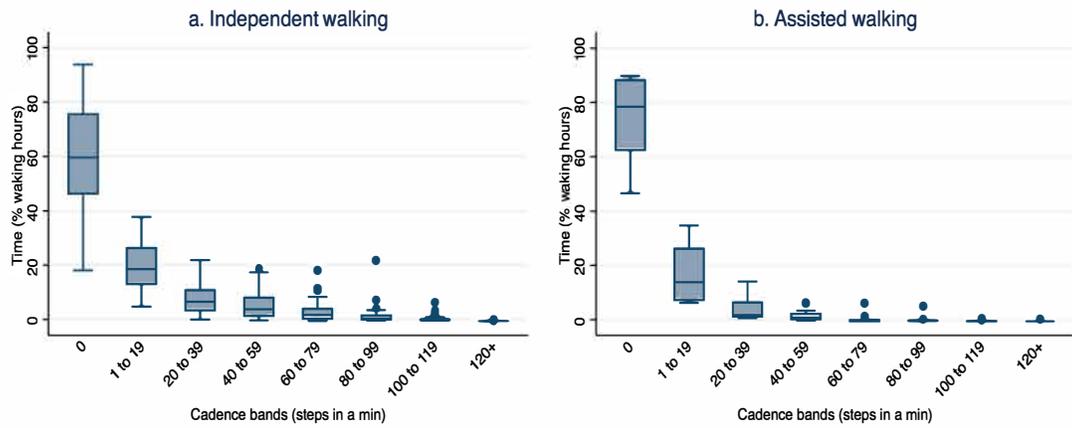


Figure 2

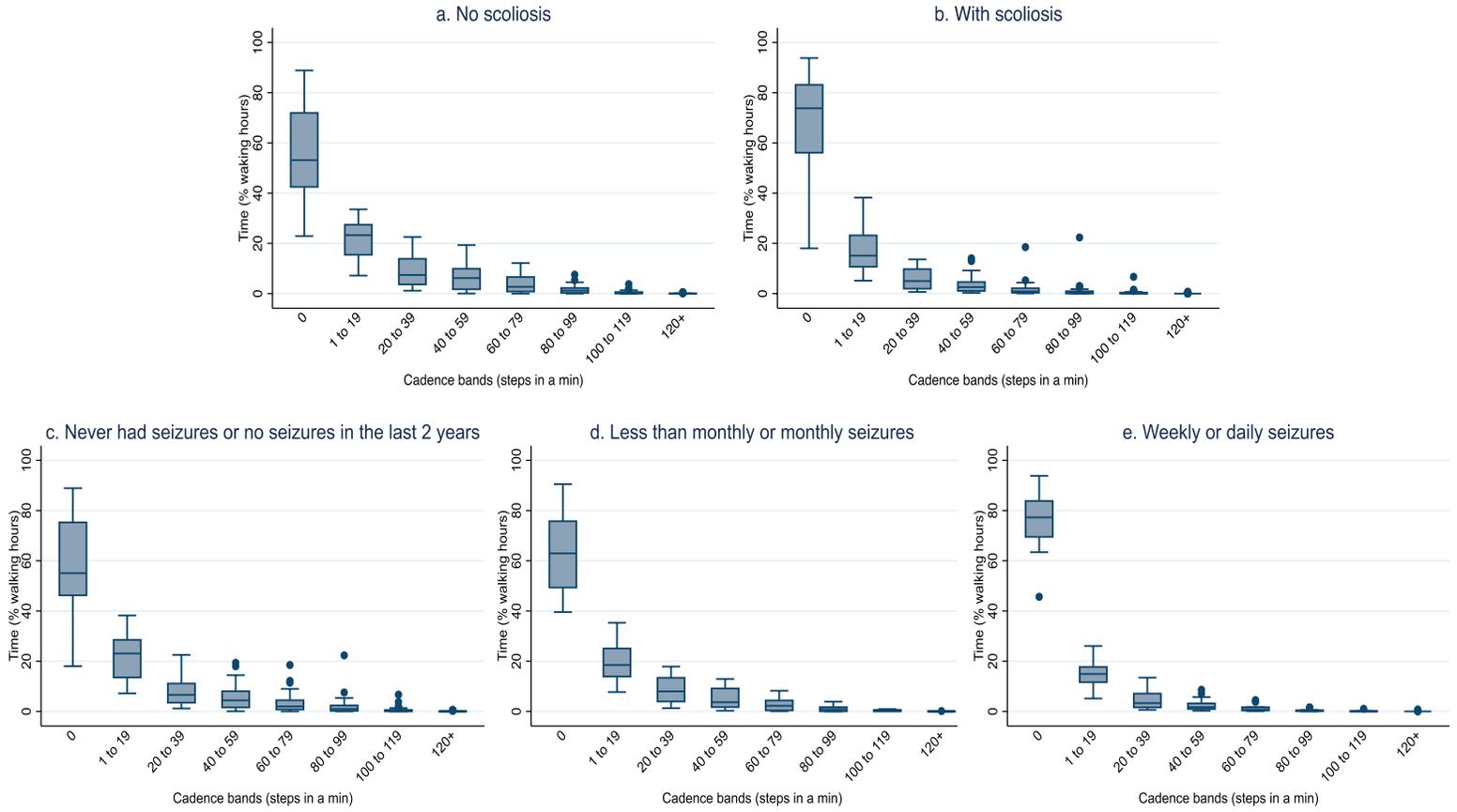


Table 1: Frequency distribution (n, %) of mutation type, age group, walking ability and comorbidity status for individuals in the Australian Rett Syndrome Database in 2012

		Able to walk independently or with assistance		Unable to walk (n=94)
		StepWatch data available (n=64)	No StepWatch data available (n=93)	
Common mutation	C-terminal deletion	9 (14.1)	9 (9.7)	8 (8.5)
	Early truncating	1 (1.6)	5 (5.4)	11 (11.7)
	Large deletion	4 (6.2)	2 (2.2)	6 (6.4)
	p.Arg106Trp	4 (6.2)	3 (3.2)	3 (3.2)
	p.Arg133Cys	7 (10.9)	10 (10.8)	1 (1.1)
	p.Arg168*	6 (9.4)	4 (4.3)	12 (12.8)
	p.Arg255*	-	8 (8.6)	7 (7.4)
	p.Arg270*	2 (3.1)	5 (5.4)	7 (7.4)
	p.Arg294*	6 (9.4)	10 (10.8)	2 (2.1)
	p.Arg306Cys	6 (9.4)	4 (4.3)	-
	p.Thr158Met	5 (7.8)	7 (7.5)	9 (9.6)
	Other	7 (10.9)	10 (10.8)	9 (9.6)
	Negative	7 (10.9)	16 (17.2)	19 (20.2)
Age	< 13 years	25 (39.1)	21 (22.6)	33 (35.1)
	13 to 18 years	11 (17.2)	21 (22.6)	23 (24.5)
	≥ 19 years	28 (43.8)	51 (55.8)	38 (40.4)
Walking ability	Unable to walk	-	-	94 (100)
	Assisted	15 (23.4)	27 (29.0)	-
	Independent	49 (76.6)	66 (71.0)	-
Scoliosis ^a	Diagnosed	32 (50.0)	59 (63.4)	80 (86.0)
Frequency of seizures ^b	Never or none in the last 2 years	33 (51.6)	33 (49.2)	28 (37.3)
	Less than monthly or monthly	17 (26.6)	19 (28.4)	21 (28.0)
	Weekly or daily	14 (21.9)	15 (22.4)	26 (34.7)

^a Scoliosis data for 93 individuals who could walk independently or with assistance who did not provide StepWatch data, and for 93 individuals who were unable to walk

^b Data for 67 individuals who could walk independently or with assistance who did not provide StepWatch data, and for 75 individuals who were unable to walk

Table 2: Univariate and multivariate estimated effects of covariates on the average daily steps (log transformed) and sedentary time (% of wear time)

Factor	Level	Average daily steps					Sedentary time				
		Median (IQR)	Univariate findings		Multivariate findings		Mean (SD)	Univariate findings		Multivariate findings	
			Coefficient (95% CI)	P value	coefficient (95% CI)	P value		Coefficient (95% CI)	P value	Coefficient (95% CI)	P value
Age	< 13 years	9,489 (5,850-12,840)	-	-	-	-	49.0 (13.9)	-	-	-	-
	13 to 18 years	8,017 (2001-10,594)	0.614 (0.331, 1.000)	0.081	0.647 (0.388, 1.081)	0.095	64.3 (22.2)	15.2 (4.3, 26.1)	0.007*	14.1 (3.6, 24.7)	0.010*
	≥ 19 years	3,250 (1,486-4,809)	0.323 (0.213, 0.491)	<0.001*	0.382 (0.260, 0.562)	<0.001*	74.4 (12.6)	25.7 (17.4, 34.0)	<0.001*	22.6 (14.6, 30.5)	<0.001*
Walking ability	Assisted	3,000 (1,336-4,139)	-	-	-	-	74.3 (15.5)	-	-	-	-
	Independent	7,580 (3,590-9,585)	2.485 (1.524, 4.053)	<0.001*	2.111 (1.419, 3.143)	0.001*	59.5 (18.6)	-14.8 (-25.4, -4.2)	0.007*	-11.4 (-19.6, -3.2)	0.007*
Scoliosis	No	8,053 (3,494-12,819)	-	-	-	-	56.6 (18.4)	-	-	-	-
	Yes	4,959 (1,680-7,077)	0.545 (0.354, 0.840)	0.007*	0.848 (0.583, 1.233)	0.382	69.4 (17.5)	12.7 (3.8, 21.7)	0.006*	2.5 (-5.2, 10.2)	0.523
Epilepsy	Never or none in the last 2 years	6,539 (2,658-10,762)	-	-	-	-	57.6 (20.1)	-	-	-	-
	Less than monthly or monthly	5,069 (2,671-9,215)	0.830 (0.494, 1.395)	0.476	1.062 (0.701, 1.611)	0.770	63.2 (16.6)	5.6 (-5.0, 16.3)	0.295	-0.3 (-8.8, 8.3)	0.948
	Weekly or daily	2,642 (1,636-5,118)	0.456 (0.262, 0.794)	0.006*	0.633 (0.406, 0.986)	0.044	75.5 (12.4)	17.9 (6.6, 29.3)	0.003*	11.1 (2.0, 20.3)	0.018*

Coefficient values for average daily steps represent the ratio of the expected geometric mean for each category in relation to the baseline category

* p<0.05