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Differing Context-Specific Sedentary Behaviors in Australian Adults with Higher and Lower Diabetes Risk

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Research

Keywords: Sedentary behavior, context-specific sitting, dysglycemia, glucose metabolism

Posted Date: September 8th, 2020

DOI: https://doi.org/10.21203/rs.3.rs-71442/v1

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Abstract

Time spent sitting in different settings can pose different risks to health. In Australian adults either with higher and lower diabetes risk, this study examined the differing compositions of self-reported sitting time accumulated in five contexts (occupational, transport, TV viewing, leisure computer-use and other). Participants (n = 3927; 60 ± 11 years; 45% male) were from the 2011–2012 assessment wave of the AusDiab study. The relative compositions of self-reported context-specific sedentary behaviors to total sitting time were compared between those with and without previously undiagnosed dysglycaemia (impaired fasting glucose, impaired glucose tolerance or newly diagnosed T2D), in working (323 with, 1646 without; 5-part composition) and non-working (433, 1525; 4-part composition) adults. For working adults, compared to those without dysglycaemia, those with undiagnosed dysglycemia spent the same proportion of time sitting at work, 3% more time sitting during transport, 9% more time sitting watching TV, 2% less time sitting using a computer for leisure, and 9% less time sitting during other activities. For non-working adults, compared to those without, those with dysglycemia spent 26% less time sitting during transport, 9% more time sitting while watching TV, 29% less time sitting using a computer for leisure, and 5% more time sitting during other activities. In addition to addressing overall sitting time, those with higher levels of diabetes risk may benefit from targeted reductions in context-specific sedentary behaviors, particularly TV viewing time. These findings also provide a case in point with potential relevance for other health problems associated with sedentary behavior.

Introduction

High volumes of time spent in sedentary behaviors are detrimentally associated with type 2 diabetes (T2D) incidence and with cardiometabolic risk biomarkers (1–5). Time spent sitting occurs across multiple context-specific behaviors, including TV viewing, at work, and during transport. Sitting in these different contexts may not be equally detrimental to health outcomes. For example, in Australian adults, accumulating sitting while watching TV or at the computer (during leisure) was found to be adversely associated with cardiometabolic risk, whereas occupational sitting was found to be relatively less harmful (6).

Excessive sitting is a particular concern for those at risk of or living with, T2D. Landmark lifestyle intervention trials have demonstrated the potential for effective prevention of T2D (7, 8). Importantly, these trials have been directed at those with previously undiagnosed conditions, particularly reflecting impaired blood glucose control. This has public health relevance, as in developed countries such as Australia, some 24% of the adult population have undiagnosed dysglycemia (impaired fasting glucose, impaired glucose tolerance and undiagnosed diabetes) (9). The main lifestyle issues targeted in the prevention of T2D are healthier bodyweight, improved diet, and achieving sufficient leisure time moderate-to-vigorous physical activity (MVPA) levels. However, in recognition that sitting time is significantly higher (~ 1hr/d) in those with dysglycaemia compared to those with normal glucose metabolism (10), it has become a priority to address sedentary behavior (11). Despite this, little is known about the profile of sedentary behaviors which constitute overall sitting time in those with underlying metabolic impairment,

and whether these differ from that of healthy individuals. These profiles are likely to differ greatly between workers and non-workers, as occupational sitting can be the largest contributor to daily sitting time on workdays (12).

Treating time spent in context-specific sedentary behaviors as being bound within a fixed composition (as distinct from treating them as absolute or stand-alone attributes) allows information to be expressed relative to each behavior within the set time frame. This accounts for inter-dependence between the different sedentary behaviors – changing time in one behavior necessitates change in one or more other behavior (13–17). In the context of diabetes risk, compositional methods can identify how variations in the specific sedentary behaviors that make up overall sitting time might differ between those who are at higher or lower diabetes risk.

We compared the relative contributions to total sitting time of five separate contexts of sedentary behavior (occupational, transport, TV-viewing, leisure time computer-use and other sitting) in a large sample of middle aged and older, working and non-working, adults with and without previously undiagnosed dysglycemia.

Methods

Participants and Procedures

The Australian Diabetes, Obesity and Lifestyle study (AusDiab) is a national longitudinal study, originally designed to examine the prevalence of diabetes and its predictors/precursors in a sample of Australian adults from urban areas and regional cities. Details of the data collection methods and response rates have been described previously (9, 18). Briefly, the baseline survey collected data from nationally representative sample of 11,247 adults in 1999–2000. Follow up studies were conducted in 2004-05 (AusDiab2) and 2011-12 (AusDiab3). In the 2011-12 data collection, new survey questions on context specific sedentary behaviors were added. The present study uses cross-sectional data from participants in AusDiab3 who attended testing sites for a biomedical examination (n = 4,614). After excluding those who: were pregnant (n = 6); had known type 2 diabetes (n = 446); known CVD (n = 189); had implausible total sitting time (greater than 18 hours per day) (n = 10) or had missing self-reported sitting time data (n = 37); the sample size for analysis was 3,927. The sample was stratified by working status, with working adults being those who reported working either full time or part time, “in a paid position, including self-employment, or as a volunteer” (n = 1,969). Non-workers included those who reported being retired, not working (but not retired), studying, or other (n = 1,958). The Alfred Hospital Ethics Committee approved the study and written informed consent was obtained from all participants.

Measurement and Data Management

Participants in AusDiab3 attended a biomedical examination which assessed a variety of biomarkers of cardiometabolic health. After an overnight fast (minimum 10 h) they attended a local testing center to complete a standard 75 g 2 h oral glucose tolerance test. Glycemic status was classified according to

1999 World Health Organization criteria (19). Participants not reporting a previous diagnosis of diabetes and who had fasting plasma glucose > 7.0 mmol/L or 2 h post-load glucose > 11.1 mmol/L were classified as having previously undiagnosed diabetes. For those without known diabetes, fasting plasma glucose > 7.0 mmol/L and 2 h post-load glucose > 7.8 but < 11.1 mmol/L indicated impaired glucose tolerance; impaired fasting glucose was defined as fasting plasma glucose > 6.1 and < 7.0 mmol/L, with 2 h post-load glucose < 7.8 mmol/L; and normal glucose tolerance was defined as fasting plasma glucose < 6.1 mmol/L and 2 h post-load glucose < 7.8 mmol/L, without prior-diagnosed diabetes.

Sitting time

Participants reported sitting time over the previous seven days, separately for weekdays and weekends, across five contexts (occupational, transport, television viewing, leisure time computer use and “other” sitting). The measurement properties of the items used have been previously reported; and, the sum of these five contexts has been validated against total sitting time measured by activPAL (r = 0.46 [95% CI: 0.40, 0.52]) (20). “Other” sitting, while difficult to interpret due to the lack of clarity regarding which behaviors are captured, was included in the analysis as it represented a significant portion of total sitting time. Average daily sitting time (h/day) for each of the five contexts [(weekday/5 + weekend/2)/7)] was then calculated. Total sitting time was calculated as the sum of all five forms of sitting (including “other”) in working adults and for the four relevant forms of sitting (excluding occupational sitting) in non-working adults.

Social and behavioral attributes:

Attributes used to describe the general health and demographic profile of the different sub-samples were determined from interviewer-administered questions and include age, gender, parental history of diabetes and educational attainment (high school or less, technical/vocational, bachelor’s degree or higher). Leisure-time physical activity (LTPA; h/day), including walking for recreation or transport, and MVPA was assessed for the previous week using the Active Australia Survey Questionnaire (Australian Institute for Health and Welfare, Canberra, Australia). Validation studies of the Active Australia questionnaire have reported good reliability and acceptable validity (21).

Statistical Analyses and Data Handling

Properties of compositional data as they relate to sitting time

Previous studies have applied compositional approaches using the 24 h waking day as the composite whole. Another approach of relevance to our study is to apply proportions (i.e. the sum of 1) to the composite of behaviors (22, 23). In the context of sitting time, this time-use can be viewed as a combination of mutually exclusive contexts in which sitting is accumulated, such as at work, during transport, while watching TV or using a computer for leisure. When individual data components are treated as compositional, the resulting information is considered to be relative as opposed to absolute; i.e. any associations evident from one component is meaningful only by reference to the other components which make up the composite whole (22).

Calculation of geometric means and isometric log ratios

Appropriate to the analytic method (22) geometric means were calculated. Subsequently, these geometric means were used to calculate the log-ratio differences in sitting times between those with and without undiagnosed dysglycemia (i.e. geometric mean occupational sitting in those with dysglycemia divided by the geometric mean occupational sitting for those with normal glucose metabolism). A positive value indicates, in this case, that those with dysglycemia spent more time sitting in that particular context than those with normal glucose metabolism, and conversely if the value is negative, less time is spent sitting. If the value is zero, the sitting time is equal across the two groups. Isometric log ratios (ILRs) were calculated for each context of sitting for each of the two groups (dysglycemia and normal glucose metabolism). The presence of zeros within compositional data presents issues as log-ratios cannot be applied to zero values (24). Given that in our case, zeros were expected (e.g. if someone reported they spent 0 h watching TV), essential zeros were assigned a very small non-zero value of 1 min/day, which allows for log transformation.

Tests for statistical significance

Standard tests (t-tests and chi-square tests) to examine differences in descriptive characteristics of the two groups were used. Hotelling's test (multivariate test) was used to determine whether there was a difference in any of the ILRs of the five contexts of sitting between those with and without undiagnosed dysglycemia. Bonferroni adjusted p-values were used to determine the significance of the test for both working and non-working groups. This test indicated whether the compositions differed overall between groups, but not which individual components differed. To examine this, we developed bootstrap percentile confidence intervals for log ratio differences for each separate component of sitting. If the confidence interval crossed zero, this indicated that there was no statistically significant difference between groups with respect to this component (23). All analyses were conducted using Stata (version 14.0 Stata Corporation, College Station,TX, USA) and RStudio (version 1.2.5033 2009–2019 RStudio, Inc.) software using the compositions (25), Hotellings (26), and boot (27) packages. Finally, though the survey used a complex sample design, we did not apply survey weights to the current analysis.

Results

Attributes of Participants

Of the 3,927 study participants; 756 had previously undiagnosed dysglycemia. Those with undiagnosed dysglycemia were older (mean ± SD, 64 ± 11 years) compared to those with normal glucose metabolism (59 ± 11 years). Less were women (48% compared to 59%), and less reporting working either full or part time (44% compared to 53%). Those with undiagnosed dysglycemia spent less time in LTPA (0.68 ± 0.75 h/day) compared to those with normal glucose metabolism (0.90 ± 0.90 h/day, $P < 0.001$), and less reported meeting at least the recommended 150 minutes of MVPA per week (57% compared to 67%). The majority of those with undiagnosed dysglycemia were categorized as either overweight or obese (82%), compared to 64% of those with normal glucose metabolism. Participant attributes by working status are

reported in Table 1. Of the 1969 who were working, 323 had previously undiagnosed dysglycemia, as did 433 of the 1958 non-working adults.

Table 1
Sociodemographic attributes, health-related and behavioral factors of the sample

	Working		**Non-working**	
	Normal Glucose Metabolism (n = 1646)	**Undiagnosed dysglycemia (n = 323)**	**Normal Glucose Metabolism (n = 1525)**	**Undiagnosed dysglycemia (n = 433)**
Age, y; mean ± SD	55 ± 9	58 ± 8	63 ± 11	68 ± 11
Female, n (%)	900 (55%)	115 (36%)	967 (63%)	248 (57%)
Parental history of diabetes, n (%)	446 (27%)	120 (37%)	391 (26%)	132 (30%)
Education, n (%)				
High school or less	432 (27%)	106 (33%)	534 (35%)	194 (45%)
Technical/vocational	725 (44%)	136 (42%)	665 (44%)	182 (42%)
Bachelor's degree or higher	478 (29%)	79 (25%)	319 (21%)	56 (11%)
Total MVPA time (min/day); mean ± SD	54 ± 54	40 ± 44	53 ± 53	41 ± 46
Meeting minimum physical activity guidelines (≥ 150 min MVPA/wk), n (%)	543 (33%)	145 (45%)	517 (34%)	178 (41%)
BMI group*, n (%)				
Normal weight	587 (36%)	45 (14%)	562 (37%)	92 (21%)
Overweight	700 (43%)	144 (45%)	625 (41%)	168 (39%)
Obese	357 (22%)	134 (41%)	337 (22%)	171 (40%)

*BMI categories used: Normal weight 18.0-24.9 $kg.m^{-2}$; Overweight; 25.0-29.9 $kg.m^{-2}$; Obese; >30.0 $kg.m^{-2}$. MVPA: Moderate-Vigorous Physical Activity

Differences Between Groups in Context-Specific Sitting Time

Mean time spent sitting in each context are presented in Table 2, separately for workers or non-workers, by glycemic status. Arithmetic means and medians are presented in absolute values (standard methods).

Compositional geometric means (calculated using Aitchison geometry) are presented as proportions of the total time sitting.

Table 2
Descriptive characteristics of the time-use composition between working and non-working adults, by glycemic status group

	Arithmetic mean (SD) h/day		Median (IQR) h/day		Geometric mean*	
Normal glucose metabolism	**Working**	**Non-working**	**Working**	**Non-working**	**Working**	**Non-working**
Total sitting	7.25 (2.86)	6.12 (2.53)	7.14 (4.02)	5.86 (3.29)	1	1
Occupational Sitting	2.64 (2.30)	N/A	2.29 (3.86)	N/A	0.25	N/A
Transport Sitting	0.89 (0.84)	0.75 (0.72)	0.71 (0.79)	0.57 (0.71)	0.15	0.14
TV-viewing	1.63 (1.16)	2.00 (1.32)	1.43 (1.43)	2 (1.86)	0.28	0.41
Leisure time computer use	0.59 (0.84)	0.64 (0.93)	0.29 (0.83)	0.29 (1)	0.05	0.06
Other sitting	1.51 (1.19)	1.89 (1.39)	1.14 (1.29)	1.64 (1.5)	0.26	0.39
Undiagnosed dysglycemia						
Total sitting	7.93 (3.11)	6.07 (2.56)	8.0 (4.48)	5.86 (3.24)	1	1
Occupational Sitting	2.98 (2.64)	N/A	2.86 (4.64)	N/A	0.24	N/A
Transport Sitting	1.01 (1.03)	0.64 (0.69)	0.76 (0.71)	0.43 (0.64)	0.16	0.11
TV-viewing	1.81 (1.22)	2.30 (1.50)	1.71 (1.93)	2 (1.86)	0.31	0.45
Leisure time computer use	0.68 (0.91)	0.68 (1.17)	0.36 (1)	0.21 (0.86)	0.05	0.04
Other sitting	0.46 (1.15)	2.13 (1.46)	1.21 (1.29)	1.71 (1.95)	0.24	0.41

*Geometric means are calculated using Aitchison geometry and are expressed as proportions of the total 1. Working adults have a 5-part time-use composition, non-working adults have a 4-part composition (No occupational sitting). SD; standard deviation, IQR; Inter-quartile range.

Working adults

Figure 1 shows the exponentiated log ratio contrasts (% differences) in each context of sitting time between those without and with dysglycemia, for working adults. Compared to those with normal glucose metabolism, those with undiagnosed dysglycemia spent similar proportions of time sitting while at work, 3% more time sitting during transport (95% CI -10, 16%), 9% more time sitting while watching TV (95% CI -5, 23%), 2% less time sitting while using a computer for leisure (95% CI -21, 20%), and 9% less time sitting for other activities (95% CI -21, 3%). The proportion of time spent in specific sedentary behaviors was not significantly different between those with and without previously undiagnosed dysglycemia (Hotelling's test; $P = 0.46$).

The variability of the composition of working adults with and without dysglycemia is described in Supplementary Tables 1 and 2 respectively. The variability or proportionality between pairs of components can be understood as indicators of the interchangeability of the specific components. In general, for working adults, the lowest levels of co-dependency were observed between sitting while at work and leisure-time computer use, meaning these behaviors were related to each other to a lesser extent. The highest level of co-dependency was observed between other sitting and transport sitting, meaning that these two behaviors had the greatest level of interchangeability.

Non-working adults

Non-workers (n = 1958) are described with only four contexts of sitting (i.e., any reported work sitting was ignored). Hotelling's test reported a p-value of $P < 0.001$, indicating that the proportion of time spent in specific sedentary behaviors was significantly different between those with and without previously undiagnosed dysglycemia. Figure 2 shows the exponentiated log ratio contrasts (% differences) in each context of sitting time between those without and with dysglycemia in non-working adults. Compared to those with normal glucose metabolism, non-working adults with undiagnosed dysglycemia spent 26% less time sitting during transport (95% CI -35, -16%), 9% more time sitting while watching TV (95% CI -0.5, 18%), 29% less time sitting while using a computer for leisure (95% CI -43, -11%), and 5% more time sitting during other activities (95% CI -4, 14%).

For non-working adults with and without undiagnosed dysglycemia, the lowest levels of co-dependence occurred between sitting while watching TV and sitting while using a computer for leisure (Supplementary Tables 3 & 4). For adults without dysglycemia, the highest levels of co-dependence or interchangeability were observed between other sitting and sitting during transport (2.13). For those with dysglycemia, the highest level of co-dependency was observed between other sitting and TV (2.44)

Discussion

In this large sample of Australian adults, we found that compared to those with normal glucose metabolism, working adults with undiagnosed dysglycemia spent the same amount of time sitting at work, more time sitting during transport (3%) and watching TV (9%), and less time sitting using computer

for leisure (2%) and during other activities (9%). In non-working adults, those with undiagnosed dysglycemia spent more time sitting while watching TV (9%), and during other activities (5%) and less time sitting during transport (26%) and using a computer for leisure (26%) compared to those with normal glucose metabolism.

To date, no studies have described the differences in time spent in interrelated contexts of sedentary behavior, between those with and without undiagnosed dysglycemia, in both working and non-working adults. Since previous experimental evidence suggests that the impacts of prolonged sitting on postprandial glycemia are greater in those who have a degree of underlying dysglycemia (28, 29), an improved understanding of the relative contribution to overall sitting of each respective sedentary behavior is clinically relevant. Irrespective of whether working or not, the observation that those with dysglycemia spent a greater proportion of time sitting watching TV, although not statistically significant, provides further support for the recent calls within clinical practice recommendations to target the reduction of specific sedentary behaviors for the prevention of T2D (11).

Extensive evidence suggests increased TV viewing time is associated with poorer cardiometabolic health (6, 30–33) and increased risk of CVD events and mortality (34–36). In comparison to other contexts of sedentary behavior, TV viewing can often occur concurrently with other detrimental health behaviors such as; poorer dietary patterns (37, 38); sitting for longer, uninterrupted periods of time; and often occurs in the evening following a large meal (39). Indeed, a recent study reported that overweight/obese adults had a lower postprandial glycemic response when sitting was interrupted during advertisement breaks on TV after an evening meal (40). Some contexts of sitting, such as TV viewing, may be more strongly linked with adverse outcomes due to the nature of the behavior itself - more habitual, less variable and easily recalled – meaning they may be more accurately measured than others (41). Time spent watching TV is also associated with lower socioeconomic status and other factors which are known to strongly influence health outcomes (30). Regardless, our results indicate that reducing and interrupting sitting while watching TV is an important target area to improve the cardiometabolic health of those with dysglycemia.

The contribution from occupational sitting to total sitting time was similar in both groups. This is not unexpected, since sitting while at work, in most cases, is less discretionary than sitting in other contexts (due to the constraints of the workplace and set working hours). Workplaces have been identified as environments which are high risk for excessive prolonged sitting. Occupational sitting contributes a high proportion of total sitting time (41), and intervention evidence supports reducing and interrupting occupational sitting time to improve markers of cardiometabolic health (42, 43). Thus, potential future initiatives within occupational health and safety regulations may contribute to improved health outcomes through reductions to overall sitting time, particularly in working adults. The current data does not allow insight into the discretionary nature of occupational sitting (i.e. whether work had to be performed seated) and as such is a limitation.

Those with undiagnosed dysglycemia spent less time sitting while using a computer for leisure than those with normal glucose metabolism (2% in workers, 29% in non-workers). A potential strategy for reducing time spent in what may be deemed, more “metabolically harmful” sedentary behaviors, for example TV viewing (6, 32, 34, 37, 44–46), aside from promoting movement, could be the reallocation of time from non-active to active sedentary behaviors. A recent study found non-active sedentary behaviors (e.g. sitting on a chair or reclining) were positively correlated with BMI, body fat % and insulin, whereas active sitting (e.g. sitting while typing on a computer) was negatively associated with the same outcomes (45). Additionally, evidence has emerged on the potential impacts of mentally-active compared to passive sedentary behaviors on mental health outcomes. Isotemporal substitution analyses reported reduced odds of depressive symptoms and clinician-diagnosed major depressive disorders when 30 minutes of passive sedentary behaviors (watching TV, listening to music) were substituted with 30 minutes of mentally-active sedentary behaviors (office work, sitting in a meeting, knitting) (47). While care should be taken so as not to promote accumulation of large volumes of sitting time in any context, it is possible that the more mentally-active behavior of leisure-time computer use provides an appropriate alternative to passive sedentary behaviors such as TV viewing. Future studies which combine objective measures of contextualized sitting with longitudinal study designs are needed to further explore the temporality of these findings. Additionally, the current data were collected between 2011–2012; the changing landscape of TV viewing will need to be considered with the rise of web-based streaming services.

Sitting accumulated in ‘other’ activities contributed greatly to overall sitting time and differed between glycemic groups. In working adults, those with dysglycemia spent 9% less time sitting during other activities than those with normal glucose metabolism. Conversely, in non-working adults, those with dysglycemia spent 5% more time sitting in other activities than those without. The survey question which collected this data was phrased; “…this could include sitting for reading or hobbies, socializing with friends or family including time on the telephone eating meals; or listening to music.” Presumably, a combination of both active and non-active sedentary behaviors are captured within this question, which makes interpretation difficult. Future studies could direct attention to expanding the self-reporting of these various behaviors to better understand their unique contributions to overall sitting time. Categorizing sedentary behaviors into non-active and active sitting (46) is one method of addressing this issue that future studies could employ.

Limitations include the cross-sectional nature of the data; one week of self-reported, recalled data gives limited detail around time of day sitting was accumulated or bout duration, and may not be representative of broader sitting patterns. The large contribution to overall sitting time from ‘other’ sitting behaviors increases the risk for biases due to residual confounding, meaning that important contexts of sitting are not captured. The level of detail obtained from the data does not provide insight on the underlying biological mechanisms which may contribute to the different sedentary behavior profiles observed. In addition, the sample was not population representative and may be prone to selection bias. Specifically, the analysis included a sample healthier than the general population, within the third wave of a cohort which was subject to some loss to follow up (48). Since the AusDiab study is limited to middle-aged/older adults, the findings are not generalizable to younger population age groups.

There are several strengths to our study, including the large and diverse sample of Australian adults incorporating measures of both fasting and post-challenge plasma glucose levels to identify those with previously undiagnosed dysglycemia. Furthermore, the context-specific sitting measurement was a novel aspect; unique to this wave of the AusDiab study. We also employed a compositional data analysis approach, which respects the inherently relative nature of time-use data by expressing the information as a set of log ratios. Most prior analyses of time-use data use statistical methods which focus on the absolute information in the data.

Conclusions And Recommendations For Future Research

In this large and diverse sample of Australian adults, those at higher risk of developing diabetes, or with newly diagnosed diabetes, spent a greater proportion of total sitting time watching TV, a similar proportion of the time sitting while at work (in working adults), and less time sitting to use a computer for leisure, than those at lower risk. Overall, our findings point to the potential benefit of public health initiatives that specifically target the contexts of sitting that we have identified. In light of recent clinical practice guidelines (49) calling for further investigation into specific components of sedentary behaviors and their influence on intermediary risk factors of disease development, knowledge gained from this study could assist in further enhancing the clinical and public health initiatives to reduce sitting and promote physical activity in those with a heightened risk of developing T2D. Future prospective studies examining contexts of sitting, including both passive and mentally-active sedentary behaviors, linked to device-based measures of movement are needed to confirm and extend these findings.

Declarations

Funding

The AusDiab study was co-coordinated by the Baker Heart and Diabetes Institute and sponsored by National Health and Medical Research Council (NHMRC grants: #233200, #1007544); Australian Government Department of Health and Ageing; Abbott Australasia Pty Ltd.; Alphapharm Pty Ltd.; Amgen Australia; AstraZeneca; Bristol-Myers Squibb; City Health Centre-Diabetes Service-Canberra; Department of Health and Community Services, Northern Territory; Department of Health and Human Services, Tasmania; Department of Health, New South Wales; Department of Health, Western Australia; Department of Health, South Australia; Department of Human Services, Victoria; Diabetes Australia; Diabetes Australia Northern Territory; Eli Lilly Australia; Estate of the Late Edward Wilson; GlaxoSmithKline; Jack Brockhoff Foundation; Janssen-Cilag; Kidney Health Australia; Marian & FH Flack Trust; Menzies Research Institute; Merck Sharp & Dohme; Novartis Pharmaceuticals; Novo Nordisk Pharmaceuticals; Pfizer Pty Ltd.; Pratt Foundation; Queensland Health; Roche Diagnostics Australia; Royal Prince Alfred Hospital, Sydney; Sanofi Aventis; and sanofi-synthelabo.

Acknowledgements

The AusDiab study acknowledges the support and assistance given by: K. Anstey, B. Atkins, B. Balkau, E. Barr, A. Cameron, S. Chadban, M. de Courten, A. Kavanagh, D. Magliano, S. Murray, K. Polkinghorne, J. Shaw, T. Welborn, P. Zimmet and all the study participants. NO and DD are supported by NHMRC Senior Principal Research Fellowships (#1003960 & #1078360) and by the Victorian Government's Operational Infrastructure Support program. The funders of this study had no role in the data analysis or interpretation of the results.

Authors' contributions

A.R.H. wrote the manuscript and assisted in data handling and analysis. P.S. conducted the statistical analysis and prepared the results. N.O. and D.W.D. assisted in the concept and design of the study and N.O., P.C.D., B.K.C., G.N.H. and D.W.D. participated in critical revision of the manuscript for intellectual content. All authors approved the final version of the manuscript. A.R.H. and D.W.D. are the guarantors of this work and, as such, had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

Ethics approval and consent to participate

The Alfred Hospital Ethics Committee approved the Australian Diabetes, Obesity and Lifestyle study (AusDiab) study (no. 39/11) and written informed consent was obtained from all participants.

Availability of data and material

Data that support the findings of this study are available on request under alicence agreement. Written applications can be made to the AusDiabSteering Committee (Dianna.Magliano@baker.edu.au).

Consent for publication

Not applicable.

Competing interests

The authors declare no conflicts of interest.

References

1. Bellettiere J, Winkler EAH, Chastin SFM, Kerr J, Owen N, Dunstan DW, et al. Associations of sitting accumulation patterns with cardio-metabolic risk biomarkers in Australian adults. PLoS One. 2017;12(6):e0180119.

2. Healy GN, Matthews CE, Dunstan DW, Winkler EA, Owen N. Sedentary time and cardio-metabolic biomarkers in US adults: NHANES 2003-06. Eur Heart J. 2011;32(5):590-7.
3. Healy GN, Winkler EA, Brakenridge CL, Reeves MM, Eakin EG. Accelerometer-derived sedentary and physical activity time in overweight/obese adults with type 2 diabetes: cross-sectional associations with cardiometabolic biomarkers. PLoS One. 2015;10(3):e0119140.
4. Owen N, Healy GN, Matthews CE, Dunstan DW. Too much sitting: the population health science of sedentary behavior. Exerc Sport Sci Rev. 2010;38(3):105-13.
5. Owen N. Sedentary behavior: understanding and influencing adults' prolonged sitting time. Prev Med. 2012;55(6):535-9.
6. Dempsey PC, Hadgraft NT, Winkler EAH, Clark BK, Buman MP, Gardiner PA, et al. Associations of context-specific sitting time with markers of cardiometabolic risk in Australian adults. Int J Behav Nutr Phys Act. 2018;15(1):114.
7. Knowler WC, Barrett-Connor E, Fowler SE, Hamman RF, Lachin JM, Walker EA, et al. Reduction in the incidence of type 2 diabetes with lifestyle intervention or metformin. N Engl J Med. 2002;346(6):393-403.
8. Tuomilehto J, Lindstrom J, Eriksson JG, Valle TT, Hamalainen H, Ilanne-Parikka P, et al. Prevention of type 2 diabetes mellitus by changes in lifestyle among subjects with impaired glucose tolerance. N Engl J Med. 2001;344(18):1343-50.
9. Dunstan DW, Zimmet PZ, Welborn TA, De Courten MP, Cameron AJ, Sicree RA, et al. The rising prevalence of diabetes and impaired glucose tolerance: the Australian Diabetes, Obesity and Lifestyle Study. Diabetes Care. 2002;25(5):829-34.
10. van der Berg JD, Stehouwer CD, Bosma H, van der Velde JH, Willems PJ, Savelberg HH, et al. Associations of total amount and patterns of sedentary behaviour with type 2 diabetes and the metabolic syndrome: The Maastricht Study. Diabetologia. 2016;59(4):709-18.
11. Colberg SR, Sigal RJ, Yardley JE, Riddell MC, Dunstan DW, Dempsey PC, et al. Physical Activity/Exercise and Diabetes: A Position Statement of the American Diabetes Association. Diabetes Care. 2016;39(11):2065-79.
12. Bennie JA, Pedisic Z, Timperio A, Crawford D, Dunstan D, Bauman A, et al. Total and domain-specific sitting time among employees in desk-based work settings in Australia. Aust N Z J Public Health. 2015;39(3):237-42.
13. Chastin SF, Palarea-Albaladejo J, Dontje ML, Skelton DA. Combined Effects of Time Spent in Physical Activity, Sedentary Behaviors and Sleep on Obesity and Cardio-Metabolic Health Markers: A Novel Compositional Data Analysis Approach. PLoS One. 2015;10(10):e0139984.
14. Foley L, Dumuid D, Atkin AJ, Olds T, Ogilvie D. Patterns of health behaviour associated with active travel: a compositional data analysis. Int J Behav Nutr Phys Act. 2018;15(1):26.
15. Ryan DJ, Wullems JA, Stebbings GK, Morse CI, Stewart CE, Onambele-Pearson GL. The difference in sleep, sedentary behaviour, and physical activity between older adults with 'healthy' and 'unhealthy'

cardiometabolic profiles: a cross-sectional compositional data analysis approach. Eur Rev Aging Phys Act. 2019;16:25.

16. Pedišić Ž, Dumuid D, S Olds T. Integrating sleep, sedentary behaviour, and physical activity research in the emerging field of time-use epidemiology: definitions, concepts, statistical methods, theoretical framework, and future directions. Kinesiology: International journal of fundamental and applied kinesiology. 2017;49(2.):252-69.
17. Gupta N, Mathiassen SE, Mateu-Figueras G, Heiden M, Hallman DM, Jorgensen MB, et al. A comparison of standard and compositional data analysis in studies addressing group differences in sedentary behavior and physical activity. Int J Behav Nutr Phys Act. 2018;15(1):53.
18. Tanamas SK, Shaw JE, Backholer K, Magliano DJ, Peeters A. Twelve-year weight change, waist circumference change and incident obesity: the Australian diabetes, obesity and lifestyle study. Obesity (Silver Spring). 2014;22(6):1538-45.
19. Alberti KG, Zimmet PZ. Definition, diagnosis and classification of diabetes mellitus and its complications. Part 1: diagnosis and classification of diabetes mellitus provisional report of a WHO consultation. Diabet Med. 1998;15(7):539-53.
20. Clark BK, Lynch BM, Winkler EA, Gardiner PA, Healy GN, Dunstan DW, et al. Validity of a multi-context sitting questionnaire across demographically diverse population groups: AusDiab3. Int J Behav Nutr Phys Act. 2015;12:148.
21. Brown WJ, Burton NW, Marshall AL, Miller YD. Reliability and validity of a modified self-administered version of the Active Australia physical activity survey in a sample of mid-age women. Aust N Z J Public Health. 2008;32(6):535-41.
22. Aitchison J. The statistical analysis of compositional data. Journal of the Royal Statistical Society: Series B (Methodological). 1982;44(2):139-60.
23. Martín Fernández JA, Daunis i Estadella J, Mateu i Figueras G. On the interpretation of differences between groups for compositional data. SORT: statistics and operations research transactions, 2015, vol 39, núm 2, p 231-252. 2015.
24. Aitchison J, Egozcue JJ. Compositional data analysis: where are we and where should we be heading? Mathematical Geology. 2005;37(7):829-50.
25. van den Boogaart K, Tolosana-Delgado R, Bren M. compositions': Compositional Data Analysis in R Package. R (version≥ 220). 2014.
26. Curran J, Curran MJ. Package 'Hotelling'. 2018.
27. Canty A, Ripley B. boot: Bootstrap R (S-Plus). Functions. 2008.
28. Dempsey PC, Larsen RN, Winkler EAH, Owen N, Kingwell BA, Dunstan DW. Prolonged uninterrupted sitting elevates postprandial hyperglycaemia proportional to degree of insulin resistance. Diabetes Obes Metab. 2018;20(6):1526-30.
29. Homer AR, Owen N, Dunstan DW. Too much sitting and dysglycemia: Mechanistic links and implications for obesity. Current Opinion in Endocrine and Metabolic Research. 2019;4:42-9.

30. Dunstan DW, Salmon J, Owen N, Armstrong T, Zimmet PZ, Welborn TA, et al. Physical activity and television viewing in relation to risk of undiagnosed abnormal glucose metabolism in adults. Diabetes Care. 2004;27(11):2603-9.
31. Hansen AL, Wijndaele K, Owen N, Magliano DJ, Thorp AA, Shaw JE, et al. Adverse associations of increases in television viewing time with 5-year changes in glucose homoeostasis markers: the AusDiab study. Diabet Med. 2012;29(7):918-25.
32. Wijndaele K, Healy GN, Dunstan DW, Barnett AG, Salmon J, Shaw JE, et al. Increased cardiometabolic risk is associated with increased TV viewing time. Med Sci Sports Exerc. 2010;42(8):1511-8.
33. Gardiner PA, Healy GN, Eakin EG, Clark BK, Dunstan DW, Shaw JE, et al. Associations between television viewing time and overall sitting time with the metabolic syndrome in older men and women: the Australian Diabetes, Obesity and Lifestyle study. J Am Geriatr Soc. 2011;59(5):788-96.
34. Grace MS, Lynch BM, Dillon F, Barr EL, Owen N, Dunstan DW. Joint associations of smoking and television viewing time on cancer and cardiovascular disease mortality. Int J Cancer. 2017;140(7):1538-44.
35. Grontved A, Hu FB. Television viewing and risk of type 2 diabetes, cardiovascular disease, and all-cause mortality: a meta-analysis. JAMA. 2011;305(23):2448-55.
36. Wijndaele K, Brage S, Besson H, Khaw KT, Sharp SJ, Luben R, et al. Television viewing time independently predicts all-cause and cardiovascular mortality: the EPIC Norfolk study. Int J Epidemiol. 2011;40(1):150-9.
37. Thorp AA, McNaughton SA, Owen N, Dunstan DW. Independent and joint associations of TV viewing time and snack food consumption with the metabolic syndrome and its components; a cross-sectional study in Australian adults. Int J Behav Nutr Phys Act. 2013;10(96):96.
38. Compernolle S, De Cocker K, Teixeira PJ, Oppert J-M, Roda C, Mackenbach JD, et al. The associations between domain-specific sedentary behaviours and dietary habits in European adults: a cross-sectional analysis of the SPOTLIGHT survey. BMC Public Health. 2016;16(1):1057.
39. Bellettiere J, Carlson JA, Rosenberg D, Singhania A, Natarajan L, Berardi V, et al. Gender and Age Differences in Hourly and Daily Patterns of Sedentary Time in Older Adults Living in Retirement Communities. PLoS One. 2015;10(8):e0136161.
40. Climie RE, Grace MS, Larsen RL, Dempsey PC, Oberoi J, Cohen ND, et al. Regular brief interruptions to sitting after a high-energy evening meal attenuate glycemic excursions in overweight/obese adults. Nutr Metab Cardiovasc Dis. 2018;28(9):909-16.
41. Hadgraft NT, Healy GN, Owen N, Winkler EA, Lynch BM, Sethi P, et al. Office workers' objectively assessed total and prolonged sitting time: Individual-level correlates and worksite variations. Prev Med Rep. 2016;4:184-91.
42. Healy GN, Eakin EG, Owen N, Lamontagne AD, Moodie M, Winkler EA, et al. A Cluster Randomized Controlled Trial to Reduce Office Workers' Sitting Time: Effect on Activity Outcomes. Med Sci Sports Exerc. 2016;48(9):1787-97.

43. Winkler EAH, Chastin S, Eakin EG, Owen N, Lamontagne AD, Moodie M, et al. Cardiometabolic Impact of Changing Sitting, Standing, and Stepping in the Workplace. Med Sci Sports Exerc. 2018;50(3):516-24.
44. Dempsey PC, Howard BJ, Lynch BM, Owen N, Dunstan DW. Associations of television viewing time with adults' well-being and vitality. Prev Med. 2014;69:69-74.
45. Suminski RR, Patterson F, Perkett M, Heinrich KM, Carlos Poston WS. The association between television viewing time and percent body fat in adults varies as a function of physical activity and sex. BMC Public Health. 2019;19(1):736.
46. Beale C, Rauff EL, O'Brien WJ, Shultz SP, Fink PW, Kruger R. Are all Sedentary Behaviors Equal? An Examination of Sedentary Behavior and Associations with Indicators of Disease Risk Factors in Women. Int J Environ Res Public Health. 2020;17(8):2643.
47. Hallgren M, Nguyen TT, Owen N, Stubbs B, Vancampfort D, Lundin A, et al. Cross-sectional and prospective relationships of passive and mentally active sedentary behaviours and physical activity with depression. Br J Psychiatry. 2019:1-7.
48. Healy GN, Winkler EA, Owen N, Anuradha S, Dunstan DW. Replacing sitting time with standing or stepping: associations with cardio-metabolic risk biomarkers. Eur Heart J. 2015;36(39):2643-9.
49. Rosenzweig JL, Bakris GL, Berglund LF, Hivert MF, Horton ES, Kalyani RR, et al. Primary Prevention of ASCVD and T2DM in Patients at Metabolic Risk: An Endocrine Society* Clinical Practice Guideline. J Clin Endocrinol Metab. 2019.

Figures

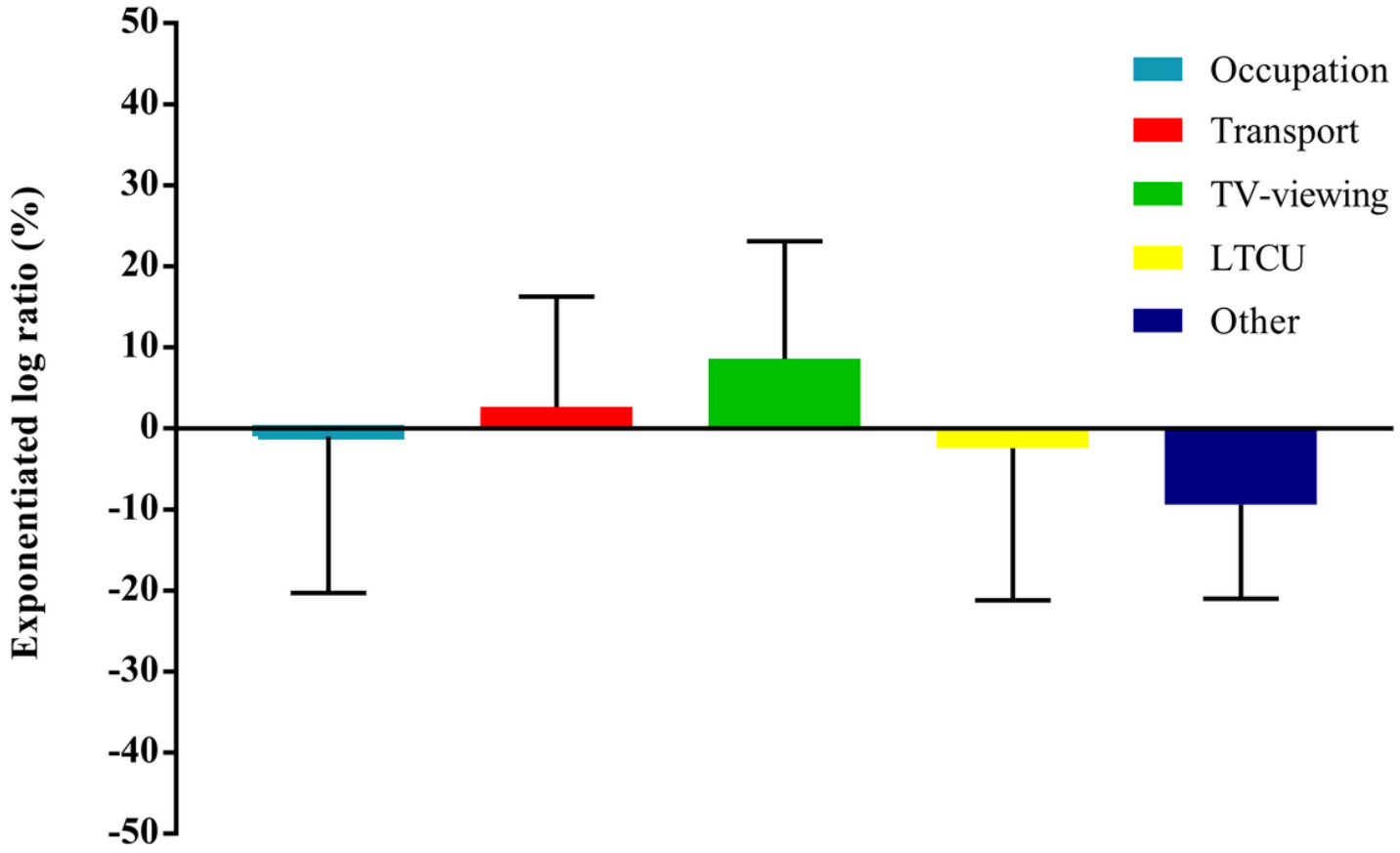

Figure 1

title: Contrasts in proportion of time spent sitting in different contexts in working adults. legend: The exponentiated isometric log ratio contrasts for the proportion of time spent sitting in different contexts between those with and without previously undiagnosed dysglycemia in working adults. Contrasts are expressed as percentages with error bars denoting bootstrap 95% Confidence Intervals. *A positive figure denotes that those with previously undiagnosed dysglycemia spend more time sitting in that context compared to those with normal glucose metabolism; a negative figure indicates less time spent sitting in those with dysglycemia compared to without. Hotelling's test P = 0.46. Statistical significance was set at P < 0.01 for working adults (5-part composition). LTCU: Leisure-time computer use.

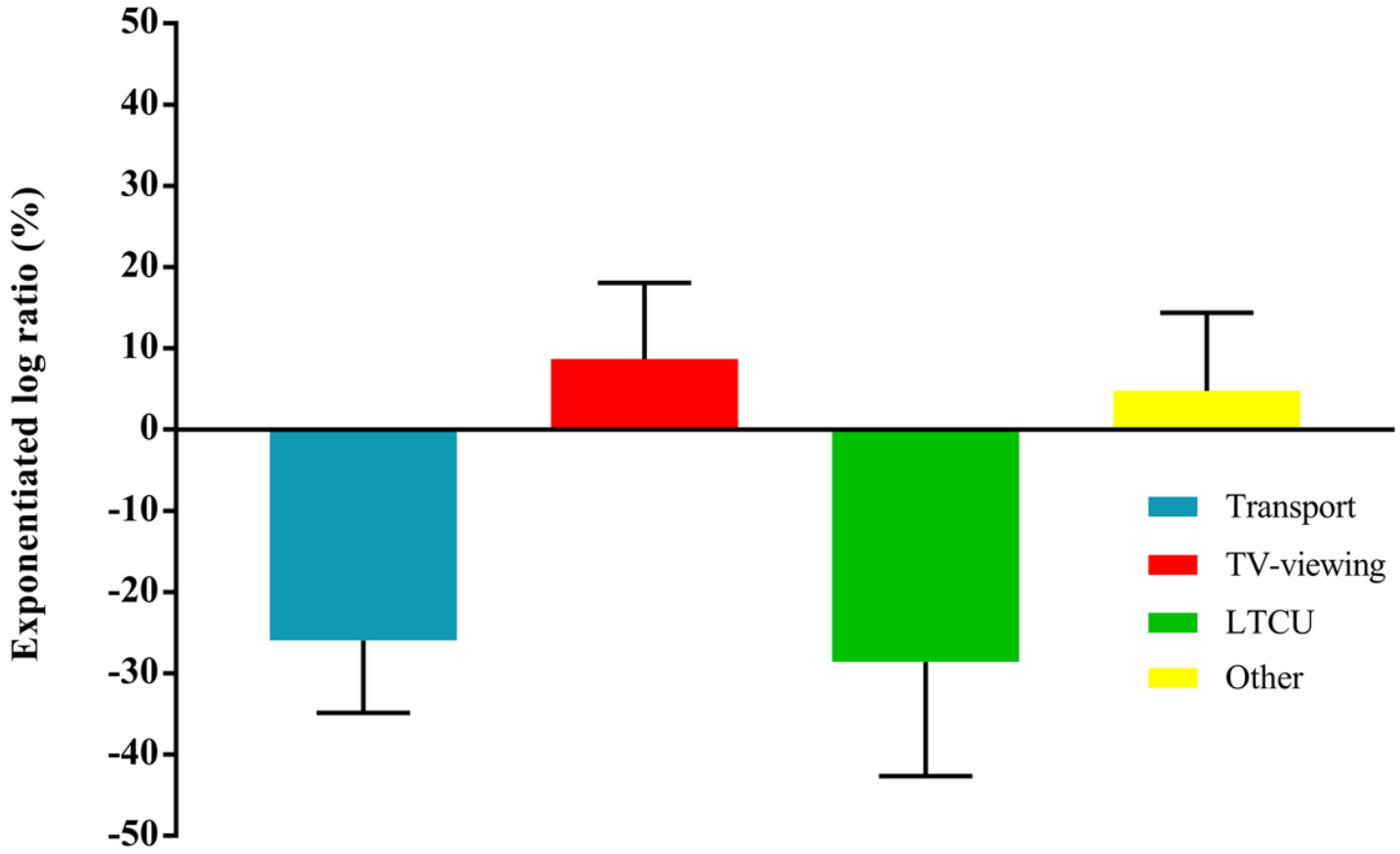

Figure 2

title: Contrasts in proportion of time spent sitting in different contexts in non-working adults. legend: The exponentiated isometric log ratio contrasts for the proportion of time spent sitting in different contexts between those with and without previously undiagnosed dysglycemia in non-working adults. Contrasts are expressed as percentages with error bars denoting bootstrap 95% Confidence Intervals. *A positive figure denotes that those with previously undiagnosed dysglycemia spend more time sitting in that context compared to those with normal glucose metabolism; a negative figure indicates less time spent sitting in those with dysglycemia compared to without. Hotelling's test $P < 0.001$. Statistical significance was set at $P < 0.0125$ for non-working adults (4-part composition). LTCU: Leisure-time computer use.