Sedentary behavior and life expectancy in the United States: A cause-deleted life table analysis

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Sedentary behavior and life expectancy in the United States: A cause-deleted life table analysis

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Abstract

Objectives: To determine the impact of sitting and television viewing on life expectancy in the United States.

Design: Prevalence-based cause-deleted life table analysis.

Setting: Summary relative risks of all-cause mortality associated with sitting and television viewing were obtained from a meta-analysis of available prospective cohort studies. Prevalences of sitting and television viewing were obtained from the U.S. National Health and Nutrition Examination Survey.

Primary Outcome Measure: Life expectancy at birth.

Results: The estimated gains in life expectancy in the US population were 1.91 years for reducing excessive sitting to less than three hours per day and a gain of 1.38 years from reducing excessive television viewing to less than 2 hours per day. The lower and upper limits from a sensitivity analysis which involved simultaneously varying the estimates of RR (using the upper and lower bounds of the 95% CI) and the prevalence of television viewing (± 20%) were 0.74 and 3.54 years for sitting and 0.48 and 2.50 years for television viewing, respectively.

Conclusions: Reducing sedentary behaviors such as sitting and television viewing has the potential to increase life expectancy in the United States.

Subject Headings: public health; epidemiology

Keywords:

Article Summary

Article focus

- This paper presents the results of an analysis aimed at determining the effects of sedentary behavior on life expectancy in the United States

Key messages

- The analyses indicate that population life expectancy in the United States would be 1.91 years higher if adults reduced their time spent sitting to less than three hours per day, and 1.38 years higher if they reduced television viewing to less than 2 hours per day.

Strengths and limitations

- The use of the well-accepted prevalence-based methodology to estimate the public health burden of sedentary behavior is a marked strength, which allows for comparability with the effects of other established risk factors.
- This study relied on self-reported engagement in sedentary behaviors rather than an objective measurement, which is a limitation.

Over 60 years of research on physical activity and health culminated in the release of the *2008 Physical Activity Guidelines for Americans*, which recommend that adults should accumulate at least 150 minutes of moderate-to-vigorous physical activity per week to attain the health benefits associated with physical activity.[1] Recently, there has been considerable interest in understanding the role of sedentary behaviors on health, independent of overall physical activity levels,[2-4] since one can be both sedentary and physically active (e.g., an office worker who sits most of his work hours, but who also jogs regularly).

Sedentary behaviors which involve sitting for extended periods are ubiquitous in modern society. Based on self-reports, a recent survey of 20 countries documented a median of 300 minutes per day spent sitting, ranging from ≤180 minutes per day in Portugal, Brazil and Colombia to ≥360 minutes per day in Taiwan, Norway, Hong Kong, Saudi Arabia and Japan.[5] Several studies have demonstrated positive associations between sedentary behaviors including sitting and television viewing and health outcomes such as type 2 diabetes, cardiovascular disease mortality and all-cause mortality.[6] Thus, excessive time spent in sedentary behavior is undoubtedly having an impact on public health. A recent study from Australia estimated that television viewing reduced life expectancy at birth by 1.8 years in men and 1.5 years in women.[7] The purpose of this study was to determine the impact of sedentary behaviors on life expectancy in the United States.

Methods

A prevalence-based approach was used to estimate the impact of sedentary behavior on life expectancy. The population-attributable fraction (PAF) was computed from the prevalences of sedentary behaviors (defined here as sitting and television viewing) and the relative risks (RR) of all-cause mortality associated with these behaviors. The PAF equation used was $\sum P_i(RR_i-1/RR_i)$, where P is the prevalence of the risk factor among cases in stratum i (i=1 to 3 in this study; details are provided below). This equation produces internally valid estimates when confounding exists and adjusted RRs must be used.[8]

Relative Risks Associated with Sedentary Behaviors

Sedentary behavior can be captured globally using questionnaires that address total daily sitting time, or time spent in specific sedentary behaviors like television viewing, reading, or computer use. Published studies on the associations between sitting or television viewing and all-cause mortality were identified through a literature search of MEDLINE. We pooled RR estimates from each study separately for sitting or television viewing and all cause-mortality using a random effects meta-analysis. Pooled RR estimates were obtained for two levels of sitting and two levels of television viewing relative to a referent group in each case. In order to maintain consistency across studies, the age- and sex-adjusted RR estimates were used from each study. In cases where the authors presented only multivariable-adjusted RR estimates, or used different exposure categories, we contacted them and asked them to provide this information. All authors contacted complied with our requests. MIX 2.0 software was used to conduct the meta-analysis.[9]

Prevalence of Sedentary Behavior

The prevalences of time spent sitting and television viewing were obtained from the National Health and Nutrition Examination Survey (NHANES). NHANES uses a complex, multistage, probability sampling design to select participants who are representative of the civilian, noninstitutionalized U.S. population.[10] The prevalence of sitting (<3 h, 3-5.9 h, and ≥6 h/day) among non-pregnant adults 18 years of age and older was determined from responses to the following question in the 2007-08 NHANES: “How much time do you usually spend sitting or reclining on a typical day?” The prevalence of television viewing (<2 h, 2-3.9 h, and ≥4 h/day) among non-pregnant adults 18 years of age and older was determined from responses to the following question in the 2005-06 NHANES: “Over the past 30 days, on average how many hours per day did you sit and watch TV or videos?” Data analysis followed the guidelines of the National Center for Health Statistics for analysis of NHANES data due to the complex sampling design and methods.[11]

The PAF equation used in this study requires the prevalence of sedentary behavior among cases (i.e. decedents) rather than from the source population (i.e. NHANES prevalence). Therefore, each population prevalences obtained from NHANES was adjusted by using the average case:source prevalence ratio (i.e. the prevalences among cases divided by the prevalences among the baseline source population from the prospective cohort studies).

Gains in Life Expectancy

The PAFs for all-cause mortality associated with sitting and television viewing were computed using the summary RR estimates obtained from the meta-analyses and the adjusted prevalences from NHANES, as described above. Potential gains in life expectancy attributable to reducing sedentary behaviors were estimated using a cause-deleted life-table analysis, which estimates years of life gained at birth if a specific cause of death is eliminated. The most current abridged life table for the United States (2009) was downloaded from the World Health Organization website.[12] The PAFs computed for sedentary behavior were used to reduce the mortality rates in the life table for adults aged 18 years and older, and the life expectancy at birth was recalculated from the new mortality rates. The difference between the current life expectancy and the cause-deleted life expectancy represents the estimated gain in life expectancy from reducing the prevalence of sedentary behavior.

Sensitivity Analysis

A sensitivity analysis was used to estimate the effects of simultaneously varying the estimates of RR (using the upper and lower bounds of the 95% CI) and the prevalences of sitting and television viewing (± 20%).

Results

The characteristics and main results of the prospective cohort studies included in the meta-analyses of sedentary behavior and mortality are presented in Table 1. Two studies were included that investigated the association between sitting and all-cause mortality.[13-14] The exposure levels of sitting in the first study were (1) none/¼ of the time, (2) ½ the time, and (3) ¾

of the time/all of the time based on activities that participants did most days of the week,[13] whereas the levels in the second study were (1) <3 h, (2) 3-5 h, and (3) ≥6 h of leisure-time sitting.[14] Three studies were included that studied the association between television viewing and all-cause mortality.[15-17] The levels of television viewing in two of the studies were (1) <2 h, (2) 2-3.9 h, and (3) ≥4 h,[15-16] whereas the levels in one study were (1) <2.5 h, (2) 2.5-3.6 h, and (3) >3.6 h.[17]

Figure 1 presents the results of the meta-analysis for sitting and all-cause mortality. The pooled relative risks were 1.18 (1.14 - 1.21) and 1.45 (1.39-1.51) for levels 2 and 3 versus level 1, respectively. Figure 2 presents the results for the meta-analysis for television viewing and all-cause mortality. The pooled relative risks were 1.17 (1.04 - 1.32) and 1.49 (1.22-1.82) for levels 2 and 3 versus level 1, respectively.

The prevalences of sitting and television viewing in cases (decedents) and in the source population at baseline in the prospective studies are presented in Table 2, along with the average case:source prevalence ratio. These ratios were applied to the population prevalences obtained from NHANES in order to estimate the prevalences among cases in the population, which are required for inclusion in the PAF calculations. Figure 3 presents the weighted population prevalences of sitting and television viewing in NHANES, along with the prevalences after adjustment for the average case:source prevalence ratios from Table 2.

The results of the life table analyses indicate a gain in life expectancy from reducing the prevalence of sedentary behavior from levels 2 or 3 to level 1 results in a gain of 1.91 years for reducing sitting prevalence and a gain of 1.38 years from reducing television viewing prevalence. The lower and upper limits from the sensitivity analyses were 0.74 and 3.54 years for sitting and 0.48 and 2.50 years for television viewing, respectively.

Discussion

The results of this study indicate that limiting sitting to less than three hours per day and limiting television viewing to less than two hours per day may increase life expectancy at birth in

the United States by approximately 1.9 and 1.4 years, respectively, assuming a causal relationship. The PAF provides a *theoretical* estimate of the effects of a risk factor on an outcome at the population level, in this case, all-cause mortality. The results indicate that sedentary behaviors are accounting for between 1.4 and 1.9 years of life expectancy at birth. This should not be interpreted to mean that people who are more sedentary can expect to live 1.4 or 1.9 years less than someone who does not engage in these behaviors as much. Life expectancy is a population statistic and it does not apply to individuals. A recent meta-analysis of television viewing and all-cause mortality estimated that the relative risk of all-cause mortality was 1.13 (95% CI: 1.07-1.18) per 2 hours of daily television viewing, which corresponded with 104 deaths per 100,000 people in the United States.[4]

This study has several strengths and limitations that warrant discussion. The use of the well-accepted prevalence-based PAF methodology to estimate the public health burden of sedentary behavior is a marked strength, which allows for comparability with the effects of other established risk factors. However, the PAF provides a *theoretical* estimate of the effects of risk factor on a health outcome, and further research is required using an incidence-based approach. Our analysis assumes that there is a causal relationship between sedentary behavior and mortality. While studies using randomized designs are not possible, further observational studies, which control for confounding, will add to the evidence for causation. Another major strength of this study is the use of representative population data from NHANES to quantify the exposure of the population to sedentary behaviors. This study relied on self-reported engagement in sedentary behaviors. Future studies should attempt to better quantify sedentary behavior using objective activity monitors; however, the estimates of sitting reported in NHANES are similar to those obtained for the U.S. in a study of 20 countries[5] which indicates some face validity to the results. For television viewing, the categories of exposure reported in the cohort studies (< 2 h, 2-3.9 h, ≥4 h) matched the categories reported in NHANES; however, the studies

on sitting used different exposure categories (i.e. total sitting time versus leisure-time sitting only), so assumptions had to made when estimating the exposure levels in NHANES.

The results of several recent studies have suggested that the effects of sedentary behavior on health may be independent of the effects of physical activity *per se*.[2 18] It has been estimated that a lack of leisure-time physical activity accounts for approximately 0.9 years of life expectancy at birth in Canada.[19] Given that the studies used to derive the summary RR estimates for the current study in many cases included leisure-time physical activity as a covariate in multivariable-adjusted models and this did not appreciably change the estimates of RR for sedentary behavior, the estimates of the effects on life expectancy may also be considered independent. Current life expectancy in the United States (2009) is 78.5 years.[12] The effects of sedentary behavior on life expectancy reported in this study are on a similar order of magnitude as other chronic disease risk factors. For example, it has been estimated that obesity accounts for between 0.30 and 1.08 years of population life expectancy at birth in the United States, depending on gender, ethnicity, and severity of obesity.[20] A more recent study has estimated that the current distribution of body mass index, compared to an optimal distribution (a mean of 21 kg/m^2), accounts for 1.3 years of current life expectancy at birth in both males and females in the United States.[21] Results from the same study indicate that smoking is also associated with 2.5 years and 1.8 years of life expectancy at birth in males and females, respectively.[21]

Sitting time is a global measure of sedentary behavior, whereas television viewing is somewhat more specific. A recent review found that domain-specific behaviors such as television viewing are recalled with more reliability than global measures of sitting and sedentary behavior.[22] The degree to which differences in reliability between the measures used in this study may have affected the estimates is not known. There is some evidence to suggest that using a single global question to measure sitting produces lower estimates than more detailed, domain-specific questions.[22-23] Thus, it is likely that the prevalences of higher levels of sitting

reported in this study from NHANES are likely conservative. Using objective monitoring (accelerometry) in the 2003-2003 NHANES, Matthews et al. reported that U.S. adults spend approximately 7.7 hours per day engaged in sedentary behavior.[24] There are several potential mechanisms that could explain the association between sedentary behavior and all-cause mortality rates. Sedentary behavior is associated with an increased risk of the development of chronic conditions such type 2 diabetes and cardiovascular disease.[6] Further, human and animal studies indicate that sedentary behavior is associated with elevated cardiometabolic biomarkers and a poor risk factor profile.[25-26] For example, hind limb suspension (unloading) in rats results in marked immediate decreases in lipoprotein lipase activity, triglyceride uptake into red skeletal muscle, and reductions in the concentration of HDL cholesterol.[27] Future intervention research is required to determine the causal pathways between sedentary behavior and health outcomes that have the potential to impact mortality rates.

In conclusion, the results of this study indicate that extended sitting time and television viewing are having a meaningful impact on life expectancy in the United States. Further research using intervention designs is required to determine the effects of reducing sedentary behavior on health outcomes and to make recommendations regarding the safe levels of sedentary behavior for the population.

Figure Legends

Figure 1. Risk of all-cause Mortality Associated with Sitting. Level 3 corresponds to ¾/all of the time for Katzmarzyk et al. 2009 and ≥6 h for Patel et al. 2010. Level 2 corresponds to ½ of the time for Katzmarzyk et al. 2009 and 3-5 h for Patel et al. 2010. Level 1 corresponds to ¼/none of the time for Katzmarzyk et al. 2009 and <3 h for Patel et al. 2010.

Figure 2. Risk of all-cause Mortality Associated with Television Viewing. Level 3 corresponds to ≥4 h for Dunstan et al. 2010 and Stamatakis et al. 2011 and ≥3.6 h for Wijndaele et al. 2011. Level 2 corresponds to 2-3.9 h for Dunstan et al. 2010 and Stamatakis et al. 2011 and 2.5-3.6 h for Wijndaele et al. 2011. Level 1 corresponds to <2 h for Dunstan et al. 2010 and Stamatakis et al. 2011 and <2.4 h for Wijndaele et al. 2011.

Figure 3. Prevalences of A) sitting and B) television viewing in the U.S. National Health and Nutrition Examination Survey. *Adjusted prevalences of sitting and television viewing using the average case/source prevalence ratio obtained from cohort studies of sedentary behavior and all-cause mortality.

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Author Contributions: Both authors were responsible study conception and design. PTK was responsible for data analysis. Both authors drafted and critically revised the manuscript, and approved the final version to be published. PTK is the guarantor for the study.

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Table 1. Characteristics and main results of the prospective cohort studies included in the meta-analysis.

Study	Participants	Age at Baseline (years)	Follow-up (years)	Person-years	Deaths (n)	Results			
Sitting Time									
Katzmarzyk et al. 2009 Canada Fitness Survey	N = 17,013 men and women	18 - 90	12	204,732	1,832		None/¼ Time	½ Time	¾ Time/All
						Deaths	826	542	464
						Person-yr	117,965	52,346	34,421
						Crude RR*	1.00	1.48	1.93
						Age-Sex-HR**	1.00	1.14	1.51
Patel et al. 2010 Cancer Prevention Study II Nutrition Cohort	N = 123,216 men and women	50 - 74	14	1,610,728	19,230		<3 h	3-5 h	≥6 h
						Deaths	7,068	9,194	2,968
						Person-yr	755,214	688,709	166,805
						Crude RR*	1.00	1.43	1.90
						Age-Sex-HR**	1.00	1.18	1.44
TV Viewing									
Dunstan et al. 2010 Australian Diabetes, Obesity and Lifestyle Study (AusDiab)	N = 8,800 men and women	≥ 25	6.6	58,087	284		<2 h	2-3.9	≥4 h
						Deaths	105	125	54
						Person-yr	33,024	20,737	4326
						Crude RR*	1.00	1.89	3.93
						Age-Sex-HR**	1.00	1.20	1.67
Stamatakis et al. 2011 Scottish Health Survey	N = 4,512 men and women	≥ 35	4.3	19,364	325		<2 h	2-3.9 h	≥4 h
						Deaths	42	138	146
						Person-yr	3,328	10,548	5,488
						Crude RR*	1.00	1.04	2.11
						Age-Sex-HR**	1.00	1.13	1.77
Wijndaele et al. 2011 EPIC - Norfolk Study	N = 13,197 men and women	45 - 79	9.5	124,902	1,270		<2.5 h	2.5-3.6 h	≥3.6 h
						Deaths	291	414	565
						Person-yr	41,936	42,288	40,680
						Crude RR*	1.00	1.41	2.17
						Age-Sex-HR**	1.00	1.17	1.32

*relative risk ratio; **age- and sex-adjusted hazard ratio.

Table 2. Prevalences of sitting and television viewing at baseline in the prospective cohort studies included in the meta-analysis.

Study	Prevalences			
Sitting Time				
Katzmarzyk et al. 2009		None/¼ Time	½ Time	¾ Time/All
	Source Prevalence (%)*	56.9	25.7	17.4
Canada Fitness Survey	Case Prevalence (%)**	45.1	29.6	25.3
	Case/Source Ratio	0.79	1.15	1.45
Patel et al. 2010		<3 h	3-5 h	≥6 h
	Source Prevalence (%)*	46.2	43.1	10.7
Cancer Prevention Study II Nutrition Cohort	Case Prevalence (%)**	36.8	47.8	15.4
	Case/Source Ratio	0.80	1.11	1.44
	Average Case/Source Ratio***	0.79	1.13	1.45
TV Viewing				
Dunstan et al. 2010		<2 h	2-3.9 h	≥4 h
	Source Prevalence (%)*	56.5	35.9	7.6
Australian Diabetes, Obesity and Lifestyle Study (AusDiab)	Case Prevalence (%)**	37.0	44.0	19.0
	Case/Source Ratio	0.65	1.23	2.50
Stamatakis et al. 2011		<2 h	2-3.9 h	≥4 h
	Source Prevalence (%)*	17.1	54.1	28.8
Scottish Health Survey	Case Prevalence (%)**	13.4	45.2	41.4
	Case/Source Ratio	0.78	0.84	1.44
Wijndaele et al. 2011		<2.5 h	2.5-3.6 h	≥3.6 h
	Source Prevalence (%)*	33.3	33.8	32.9
EPIC - Norfolk Study	Case Prevalence (%)**	22.9	32.6	44.5
	Case/Source Ratio	0.69	0.96	1.35
	Average Case/Source Ratio***	0.71	1.01	1.76

*prevalences of sitting or TV viewing in the source population at baseline; **prevalences of sitting or TV viewing in cases (decedents) at baseline; ***average case/source prevalence ratio from the prospective cohort studies.

Figure 1.

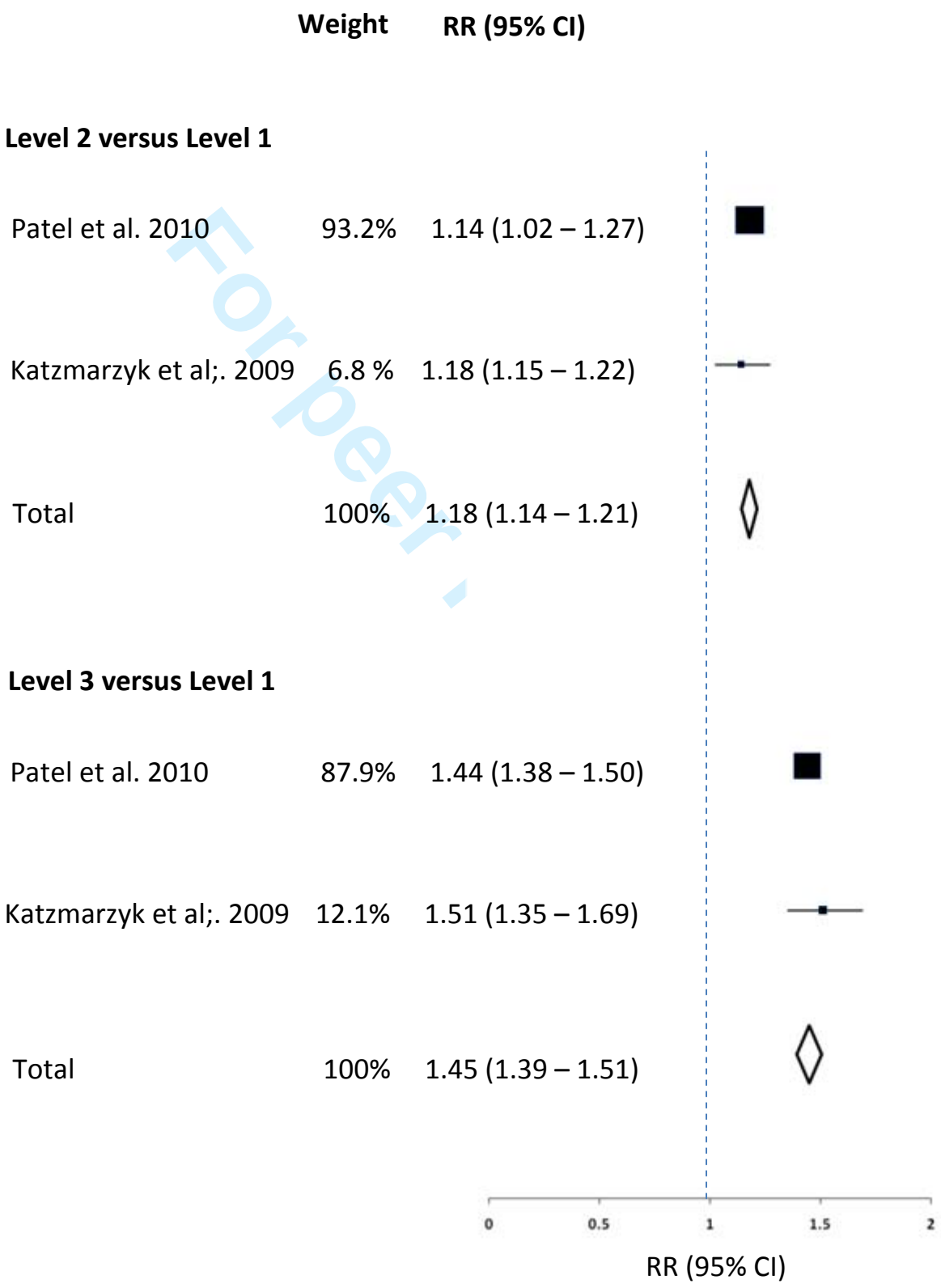


Figure 2.

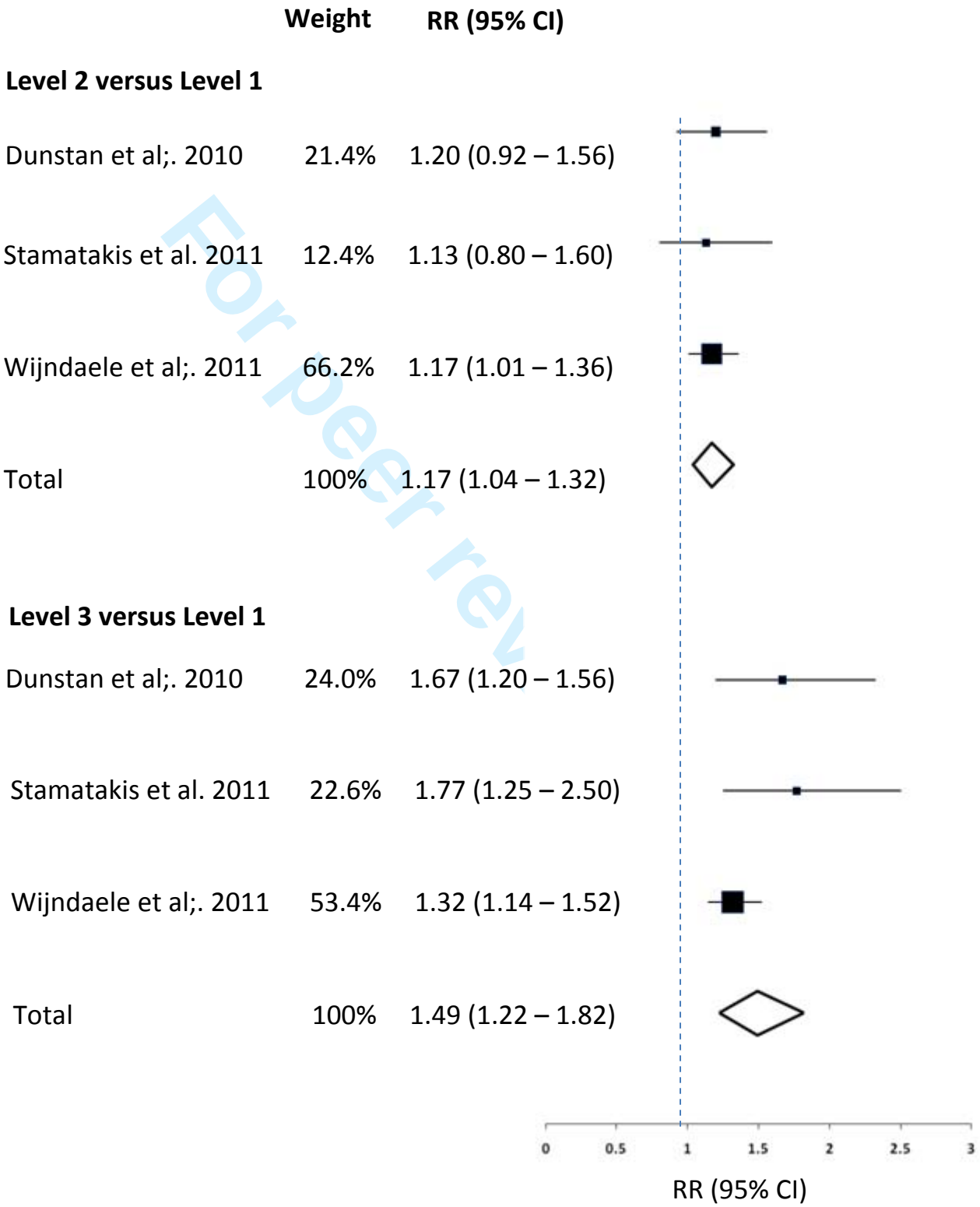
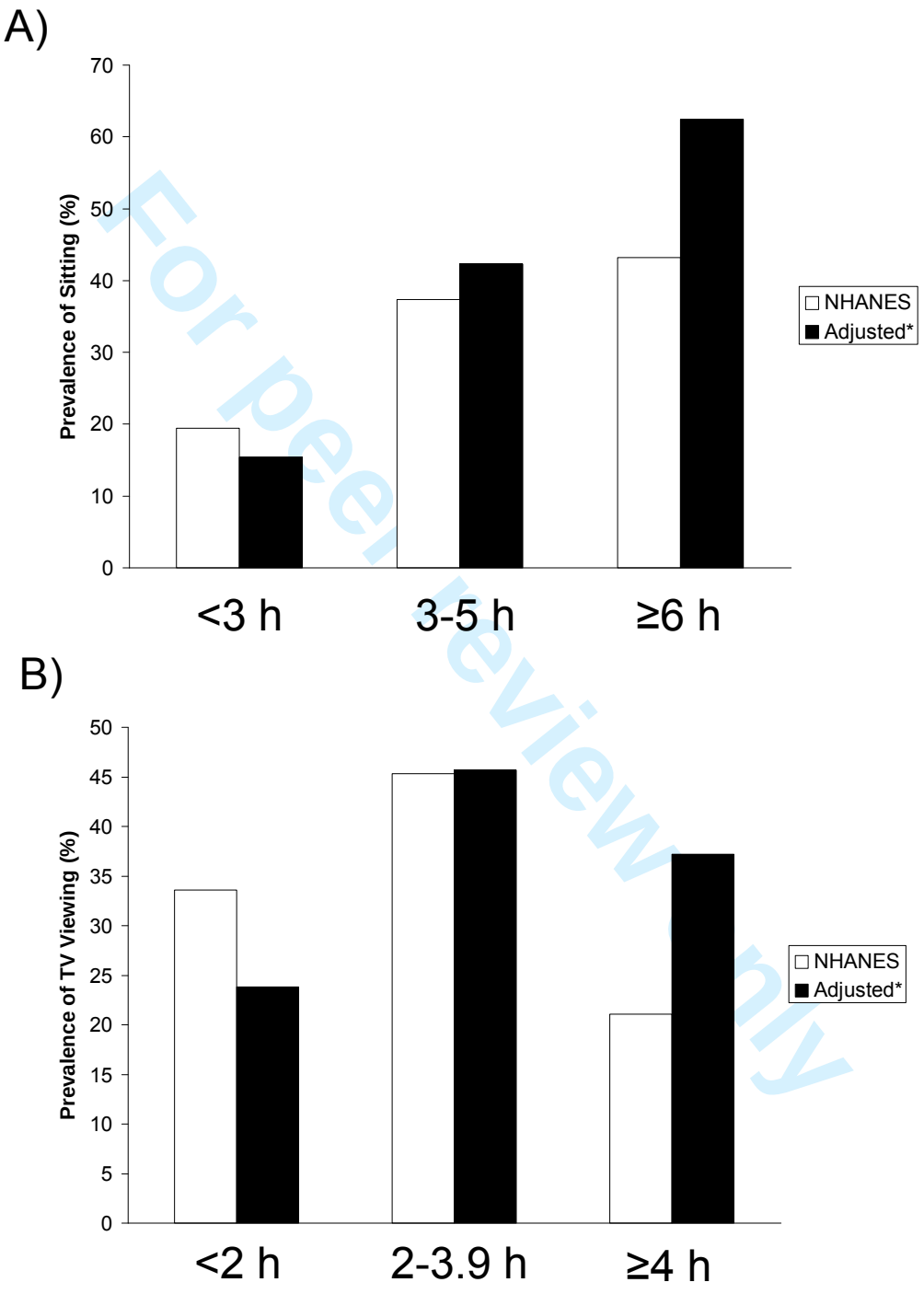


Figure 3.



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Abstract

Objectives: To determine the impact of sitting and television viewing on life expectancy in the United States.

Design: Prevalence-based cause-deleted life table analysis.

Setting: Summary relative risks of all-cause mortality associated with sitting and television viewing were obtained from a meta-analysis of available prospective cohort studies. Prevalences of sitting and television viewing were obtained from the U.S. National Health and Nutrition Examination Survey.

Primary Outcome Measure: Life expectancy at birth.

Results: The estimated gains in life expectancy in the US population were 2.00 years for reducing excessive sitting to less than three hours per day and a gain of 1.38 years from reducing excessive television viewing to less than two hours per day. The lower and upper limits from a sensitivity analysis which involved simultaneously varying the estimates of RR (using the upper and lower bounds of the 95% CI) and the prevalence of television viewing (± 20%) were 1.39 and 2.69 years for sitting and 0.48 and 2.51 years for television viewing, respectively.

Conclusions: Reducing sedentary behaviors such as sitting and television viewing has the potential to increase life expectancy in the United States.

Subject Headings: public health; epidemiology

Keywords: Preventive medicine; physical activity; lifestyle

Article Summary

Article focus

- This paper presents the results of an analysis aimed at determining the effects of sedentary behavior on life expectancy in the United States

Key messages

- The analyses indicate that population life expectancy in the United States would be 2.00 years higher if adults reduced their time spent sitting to less than three hours per day, and 1.38 years higher if they reduced television viewing to less than two hours per day.

Strengths and limitations

- The use of the well-accepted prevalence-based methodology to estimate the public health burden of sedentary behavior is a marked strength, which allows for comparability with the effects of other established risk factors.
- This study relied on self-reported engagement in sedentary behaviors rather than an objective measurement, which is a limitation.

Over 60 years of research on physical activity and health culminated in the release of the *2008 Physical Activity Guidelines for Americans*, which recommend that adults should accumulate at least 150 minutes of moderate-to-vigorous physical activity per week to attain the health benefits associated with physical activity.[1] Recently, there has been considerable interest in understanding the role of sedentary behaviors on health, independent of overall physical activity levels,[2-4] since one can be both sedentary and physically active (e.g., an office worker who sits most of his work hours, but who also jogs regularly).

Sedentary behaviors which involve sitting for extended periods are ubiquitous in modern society. Based on self-reports, a recent survey of 20 countries documented a median of 300 minutes per day spent sitting, ranging from ≤180 minutes per day in Portugal, Brazil and Colombia to ≥360 minutes per day in Taiwan, Norway, Hong Kong, Saudi Arabia and Japan.[5] Several studies have demonstrated positive associations between sedentary behaviors including sitting and television viewing and health outcomes such as type 2 diabetes, cardiovascular disease mortality and all-cause mortality.[6] Thus, excessive time spent in sedentary behavior is undoubtedly having an impact on public health. A recent study from Australia estimated that television viewing reduced life expectancy at birth by 1.8 years in men and 1.5 years in women.[7] The purpose of this study was to determine the impact of sedentary behaviors on life expectancy in the United States.

Methods

A prevalence-based approach was used to estimate the impact of sedentary behavior on life expectancy. The population-attributable fraction (PAF) was computed from the prevalences of sedentary behaviors (defined here as sitting and television viewing) and the relative risks (RR) of all-cause mortality associated with these behaviors. The PAF equation used was $\sum P_i(RR_i-1/RR_i)$, where P is the prevalence of the risk factor among cases in stratum i (i=1 to 3 in this study; details are provided below). This equation produces internally valid estimates when confounding exists and adjusted RRs must be used.[8]

Relative Risks Associated with Sedentary Behaviors

Sedentary behavior can be captured globally using questionnaires that address total daily sitting time, or time spent in specific sedentary behaviors like television viewing, reading, or computer use. Published studies on the associations between sitting or television viewing and all-cause mortality were identified through a literature search of MEDLINE using search terms related to the purpose of this study ("physical inactivity", "sedentary", "cohort study", "mortality" and "death"). Studies which reported on the relationship between sedentary and outcomes other than all-cause mortality were excluded from consideration. We pooled RR estimates from each study separately for sitting or television viewing and all cause-mortality using a random effects meta-analysis. Pooled RR estimates were obtained for two levels of sitting and two levels of television viewing relative to a referent group in each case. In order to maintain consistency across studies, the age- and sex-adjusted RR estimates were used from each study. In cases where the authors presented only multivariable-adjusted RR estimates, or used different exposure categories, we contacted them and asked them to provide this information. MIX 2.0 software was used to conduct the meta-analysis.[9]

Prevalence of Sedentary Behavior

The prevalences of time spent sitting and television viewing were obtained from the National Health and Nutrition Examination Survey (NHANES). NHANES uses a complex, multistage, probability sampling design to select participants who are representative of the civilian, noninstitutionalized U.S. population.[10] The prevalences were obtained from the most recent NHANES data available for adults (2009-2010 for sitting; 2005-2006 for television viewing). The prevalence of sitting (<3 h, 3-5.9 h, and ≥6 h/day) among non-pregnant adults 18 years of age and older was determined from responses to the following question in the 2009-10 NHANES: "How much time do you usually spend sitting on a typical day?" The prevalence of television viewing (<2 h, 2-3.9 h, and ≥4 h/day) among non-pregnant adults 18 years of age and older was determined from responses to the following question in the 2005-06 NHANES: "Over the past

30 days, on average how many hours per day did you sit and watch TV or videos?" Data analysis followed the guidelines of the National Center for Health Statistics for analysis of NHANES data due to the complex sampling design and methods.[11]

The PAF equation used in this study requires the prevalence of sedentary behavior among cases (i.e. decedents) rather than from the source population (i.e. NHANES prevalence). Therefore, each population prevalences obtained from NHANES was adjusted by using the weighted average case:source prevalence ratio (i.e. the prevalences among cases divided by the prevalences among the baseline source population from the prospective cohort studies).

Gains in Life Expectancy

The PAFs for all-cause mortality associated with sitting and television viewing were computed using the summary RR estimates obtained from the meta-analyses and the adjusted prevalences from NHANES, as described above. Potential gains in life expectancy attributable to reducing sedentary behaviors were estimated using a cause-deleted life table analysis, which estimates years of life gained at birth if deaths from a specific cause are eliminated from the current death rates.[12 13] The most current abridged life table for the United States (2009) was downloaded from the World Health Organization website.[14] The PAFs computed for sedentary behavior were used to reduce the mortality rates in the life table for adults aged 18 years and older, and the life expectancy at birth was recalculated from the new mortality rates. The difference between the current life expectancy and the cause-deleted life expectancy represents the estimated gain in life expectancy from reducing the prevalence of sedentary behavior.

Sensitivity Analysis

A sensitivity analysis was used to estimate the effects of simultaneously varying the estimates of RR (using the upper and lower bounds of the 95% CI) and the prevalences of sitting and television viewing (± 20%).

Results

The characteristics and main results of the prospective cohort studies included in the meta-analyses of sedentary behavior and mortality are presented in Table 1. Two studies were included that investigated the association between sitting and all-cause mortality.[15 16] The exposure levels of sitting in the first study were (1) none/¼ of the time, (2) ½ the time, and (3) ¾ of the time/all of the time based on activities that participants did most days of the week,[15] whereas the levels in the second study were (1) <3 h, (2) 3-5 h, and (3) ≥6 h of leisure-time sitting.[16] Thus, three categories of exposure were used in each cohort study, and the prevalence of sitting categories from NHANES were obtained for three groups (<3 h, 3-5.9 h, and ≥6 h/day). However, given that the exposure categories from the Canadian cohort study were not quantifiable in terms of absolute hours/day, some misclassification may have occurred when combining the results.

Three studies were included that studied the association between television viewing and all-cause mortality.[17-19] The levels of television viewing in two of the studies were (1) <2 h, (2) 2-3.9 h, and (3) ≥4 h,[17 18] whereas the levels in one study were (1) <2.5 h, (2) 2.5-3.6 h, and (3) >3.6 h.[19] The prevalence of television viewing obtained from NHANES (<2 h, 2-3.9 h, and ≥4 h/day) match quite well with the exposure categories from the cohort studies.

Figure 1 presents the results of the meta-analysis for sitting and all-cause mortality. The pooled relative risks were 1.18 (1.14 - 1.21) and 1.45 (1.39-1.51) for levels 2 and 3 versus level 1, respectively. Figure 2 presents the results for the meta-analysis for television viewing and all-cause mortality. The pooled relative risks were 1.17 (1.04 - 1.32) and 1.49 (1.22-1.82) for levels 2 and 3 versus level 1, respectively.

The prevalences of sitting and television viewing in cases (decedents) and in the source population at baseline in the prospective studies are presented in Table 2, along with the average case:source prevalence ratio. These ratios were applied to the population prevalences obtained from NHANES in order to estimate the prevalences among cases in the population,

which are required for inclusion in the PAF calculations. Figure 3 presents the weighted population prevalences of sitting and television viewing in NHANES, along with the prevalences after adjustment for the average case:source prevalence ratios from Table 2.

The PAFs for all-cause mortality associated with sitting and television viewing were 27% and 19%, respectively. The results of the life table analyses indicate a gain in life expectancy from reducing the prevalence of sedentary behavior from levels 2 or 3 to level 1 results in a gain of 2.00 years for reducing sitting prevalence and a gain of 1.38 years from reducing television viewing prevalence. The lower and upper limits from the sensitivity analyses were 1.39 and 2.69 years for sitting and 0.48 and 2.51 years for television viewing, respectively.

Discussion

The results of this study indicate that limiting sitting to less than three hours per day and limiting television viewing to less than two hours per day may increase life expectancy at birth in the United States by approximately 2.0 and 1.4 years, respectively, assuming a causal relationship. The PAF provides a *theoretical* estimate of the effects of a risk factor on an outcome at the population level, in this case, all-cause mortality. The results indicate that sedentary behaviors are accounting for between 1.4 and 2.0 years of life expectancy at birth. This should not be interpreted to mean that people who are more sedentary can expect to live 1.4 or 2.0 years less than someone who does not engage in these behaviors as much. Life expectancy is a population statistic and it does not apply to individuals. A recent meta-analysis of television viewing and all-cause mortality estimated that the relative risk of all-cause mortality was 1.13 (95% CI: 1.07-1.18) per 2 hours of daily television viewing, which corresponded with 104 deaths per 100,000 people in the United States.[4]

This study has several strengths and limitations that warrant discussion. The use of the well-accepted prevalence-based PAF methodology to estimate the public health burden of sedentary behavior is a marked strength, which allows for comparability with the effects of other established risk factors. However, the PAF provides a *theoretical* estimate of the effects of risk

factor on a health outcome, and further research is required using an incidence-based approach. Our analysis assumes that there is a causal relationship between sedentary behavior and mortality. While studies using randomized designs are not possible, further observational studies, which control for confounding, will add to the evidence for causation. Another major strength of this study is the use of representative population data from NHANES to quantify the exposure of the population to sedentary behaviors. However, our analysis estimated the overall gains in life expectancy at the population level, and assumes that the effects of sedentary time on all-cause mortality are consistent across age and demographic sub-groups of the population. Each of the cohort studies provided multivariable-adjusted RR estimates for sedentary behavior and mortality using different combinations of covariates, and we chose to use summary RR estimates based on RR adjusted for age and sex in order to maintain consistency across studies. The degree to which this approach has yielded an overestimation of the independent effect of sedentary behavior on life expectancy is not known.

This study relied on self-reported engagement in sedentary behaviors which introduces the possibility for error and recall bias. Future cohort studies should attempt to better quantify sedentary behavior using objective activity monitors; however, the self-reported estimates of sitting reported in NHANES are similar to those obtained for the U.S. in a study of 20 countries[5] which indicates some face validity to the results. For television viewing, the categories of exposure reported in two of the cohort studies (< 2 h, 2-3.9 h, ≥ 4 h) matched the categories reported in NHANES; however, Wijndaele et al.[19] used a lower threshold for the upper category (> 3.6 h) which may have resulted in an underestimate of the effects of television viewing on life expectancy. The studies on sitting used different exposure categories (i.e. total sitting time versus leisure-time sitting only), so assumptions had to made when estimating the exposure levels in NHANES. Inaccuracies associated with the assessment of sedentary behavior using self-report methods in the cohort studies would have led to regression dilution bias, and resulted in under-estimates of the association with all-cause mortality.

The results of several recent studies have suggested that the effects of sedentary behavior on health may be independent of the effects of physical activity *per se*.[2 20] It has been estimated that a lack of leisure-time physical activity accounts for approximately 0.9 years of life expectancy at birth in Canada.[21] Given that the studies used to derive the summary RR estimates for the current study in many cases included leisure-time physical activity as a covariate in multivariable-adjusted models and this did not appreciably change the estimates of RR for sedentary behavior, the estimates of the effects on life expectancy may also be considered independent. Current life expectancy in the United States (2009) is 78.5 years.[14] The effects of sedentary behavior on life expectancy reported in this study are on a similar order of magnitude as other chronic disease risk factors. For example, it has been estimated that obesity accounts for between 0.30 and 1.08 years of population life expectancy at birth in the United States, depending on gender, ethnicity, and severity of obesity.[22] A more recent study has estimated that the current distribution of body mass index, compared to an optimal distribution (a mean of 21 kg/m^2), accounts for 1.3 years of current life expectancy at birth in both males and females in the United States.[23] Results from the same study indicate that smoking is also associated with 2.5 years and 1.8 years of life expectancy at birth in males and females, respectively.[23]

Sitting time is a global measure of sedentary behavior, whereas television viewing is somewhat more specific. A recent review found that domain-specific behaviors such as television viewing are recalled with more reliability than global measures of sitting and sedentary behavior.[24] The degree to which differences in reliability between the measures used in this study may have affected the estimates is not known. There is some evidence to suggest that using a single global question to measure sitting produces lower estimates than more detailed, domain-specific questions.[24 25] Thus, it is likely that the prevalences of higher levels of sitting reported in this study from NHANES are likely conservative. Using objective monitoring (accelerometry) in the 2003-2003 NHANES, Matthews et al. reported that U.S. adults spend

approximately 7.7 hours per day engaged in sedentary behavior.[26] There are several potential mechanisms that could explain the association between sedentary behavior and all-cause mortality rates. Sedentary behavior is associated with an increased risk of the development of chronic conditions such type 2 diabetes and cardiovascular disease.[6] Further, human and animal studies indicate that sedentary behavior is associated with elevated cardiometabolic biomarkers and a poor risk factor profile.[27 28] For example, hind limb suspension (unloading) in rats results in marked immediate decreases in lipoprotein lipase activity, triglyceride uptake into red skeletal muscle, and reductions in the concentration of HDL cholesterol.[29] Future intervention research is required to determine the causal pathways between sedentary behavior and health outcomes that have the potential to impact mortality rates.

In conclusion, the results of this study indicate that extended sitting time and television viewing are having a meaningful impact on life expectancy in the United States. Given that the results from objective monitoring of sedentary time in NHANES has indicated that adults spend an average of 55% of their day engaged in sedentary pursuits[26], a significant shift in behavior change at the population level is required to make demonstrable improvements in life expectancy. Further research using intervention designs is required to determine the effects of reducing sedentary behavior on health outcomes and to make recommendations regarding the safe levels of sedentary behavior for the population.

Figure Legends

Figure 1. Risk of all-cause Mortality Associated with Sitting. Level 3 corresponds to ¾/all of the time for Katzmarzyk et al. 2009 and ≥6 h for Patel et al. 2010. Level 2 corresponds to ½ of the time for Katzmarzyk et al. 2009 and 3-5 h for Patel et al. 2010. Level 1 corresponds to ¼/none of the time for Katzmarzyk et al. 2009 and <3 h for Patel et al. 2010.

Figure 2. Risk of all-cause Mortality Associated with Television Viewing. Level 3 corresponds to ≥4 h for Dunstan et al. 2010 and Stamatakis et al. 2011 and ≥3.6 h for Wijndaele et al. 2011. Level 2 corresponds to 2-3.9 h for Dunstan et al. 2010 and Stamatakis et al. 2011 and 2.5-3.6 h for Wijndaele et al. 2011. Level 1 corresponds to <2 h for Dunstan et al. 2010 and Stamatakis et al. 2011 and <2.4 h for Wijndaele et al. 2011.

Figure 3. Prevalences of A) sitting and B) television viewing in the U.S. National Health and Nutrition Examination Survey. *Adjusted prevalences of sitting and television viewing using the weighted average case/source prevalence ratio obtained from cohort studies of sedentary behavior and all-cause mortality.

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Data Sharing Statement: There are no additional data available.

Author Contributions: Both authors were responsible study conception and design. PTK was responsible for data analysis. Both authors drafted and critically revised the manuscript, and approved the final version to be published. PTK is the guarantor for the study.

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Table 1. Characteristics and main results of the prospective cohort studies included in the meta-analysis.

Study	Participants	Age at Baseline (years)	Follow-up (years)	Person-years	Deaths (n)	Results			
Sitting Time									
Katzmarzyk et al. 2009 Canada Fitness Survey	N = 17,013 men and women	18 - 90	12	204,732	1,832		None/¼ Time	½ Time	¾ Time/All
						Deaths	826	542	464
						Person-yr	117,965	52,346	34,421
						Crude RR*	1.00	1.48	1.93
						Age-Sex-HR**	1.00	1.14	1.51
Patel et al. 2010 Cancer Prevention Study II Nutrition Cohort	N = 123,216 men and women	50 - 74	14	1,610,728	19,230		<3 h	3-5 h	≥6 h
						Deaths	7,068	9,194	2,968
						Person-yr	755,214	688,709	166,805
						Crude RR*	1.00	1.43	1.90
						Age-Sex-HR**	1.00	1.18	1.44
TV Viewing									
Dunstan et al. 2010 Australian Diabetes, Obesity and Lifestyle Study (AusDiab)	N = 8,800 men and women	≥ 25	6.6	58,087	284		<2 h	2-3.9	≥4 h
						Deaths	105	125	54
						Person-yr	33,024	20,737	4326
						Crude RR*	1.00	1.89	3.93
						Age-Sex-HR**	1.00	1.20	1.67
Stamatakis et al. 2011 Scottish Health Survey	N = 4,512 men and women	≥ 35	4.3	19,364	325		<2 h	2-3.9 h	≥4 h
						Deaths	42	138	146
						Person-yr	3,328	10,548	5,488
						Crude RR*	1.00	1.04	2.11
						Age-Sex-HR**	1.00	1.13	1.77
Wijndaele et al. 2011 EPIC - Norfolk Study	N = 13,197 men and women	45 - 79	9.5	124,902	1,270		<2.5 h	2.5-3.6 h	≥3.6 h
						Deaths	291	414	565
						Person-yr	41,936	42,288	40,680
						Crude RR*	1.00	1.41	2.17
						Age-Sex-HR**	1.00	1.17	1.32

*relative risk ratio; **age- and sex-adjusted hazard ratio.

Table 2. Prevalences of sitting and television viewing at baseline in the prospective cohort studies included in the meta-analysis.

Study	Prevalences			
Sitting Time				
Katzmarzyk et al. 2009		None/¼ Time	½ Time	¾ Time/All
	Source Prevalence (%)*	56.9	25.7	17.4
Canada Fitness Survey	Case Prevalence (%)**	45.1	29.6	25.3
	Case/Source Ratio	0.79	1.15	1.45
Patel et al. 2010		<3 h	3-5 h	≥6 h
	Source Prevalence (%)*	46.2	43.1	10.7
Cancer Prevention Study II Nutrition Cohort	Case Prevalence (%)**	36.8	47.8	15.4
	Case/Source Ratio	0.80	1.11	1.44
	Average Case/Source Ratio***	0.80	1.11	1.44
TV Viewing				
Dunstan et al. 2010		<2 h	2-3.9 h	≥4 h
	Source Prevalence (%)*	56.5	35.9	7.6
Australian Diabetes, Obesity and Lifestyle Study (AusDiab)	Case Prevalence (%)**	37.0	44.0	19.0
	Case/Source Ratio	0.65	1.23	2.50
Stamatakis et al. 2011		<2 h	2-3.9 h	≥4 h
	Source Prevalence (%)*	17.1	54.1	28.8
Scottish Health Survey	Case Prevalence (%)**	13.4	45.2	41.4
	Case/Source Ratio	0.78	0.84	1.44
Wijndaele et al. 2011		<2.5 h	2.5-3.6 h	≥3.6 h
	Source Prevalence (%)*	33.3	33.8	32.9
EPIC - Norfolk Study	Case Prevalence (%)**	22.9	32.6	44.5
	Case/Source Ratio	0.69	0.96	1.35
	Average Case/Source Ratio***	0.69	1.03	1.75

*prevalences of sitting or TV viewing in the source population at baseline; **prevalences of sitting or TV viewing in cases (decedents) at baseline; ***weighted-average case/source prevalence ratio from the prospective cohort studies.

Figure 1.

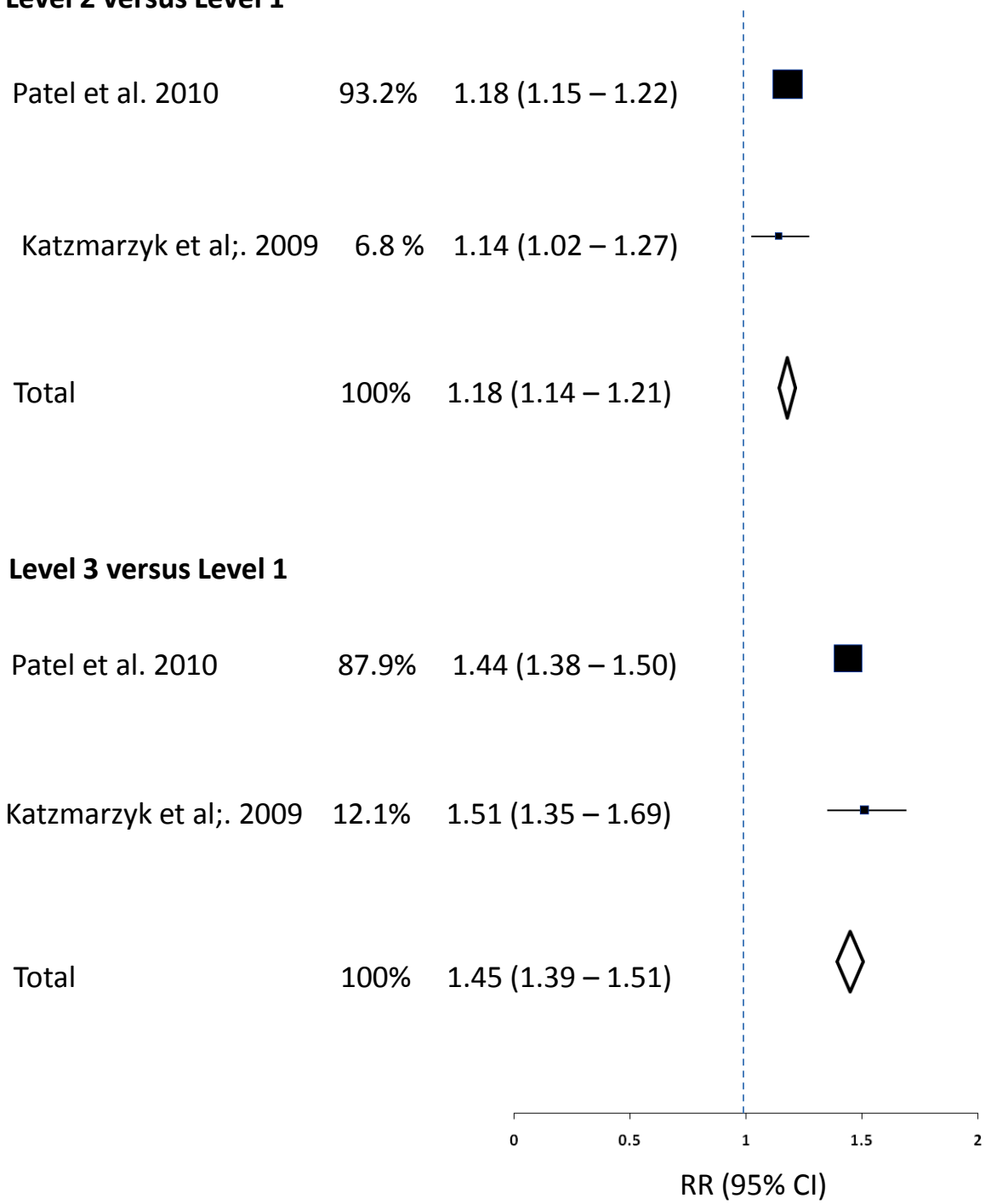
Weight
RR (95% CI)
Level 2 versus Level 1
Patel et al. 2010
93.2%
1.18 (1.15 – 1.22)
Katzmarzyk et al;. 2009
6.8 %
1.14 (1.02 – 1.27)
Total
100%
1.18 (1.14 – 1.21)
Level 3 versus Level 1
Patel et al. 2010
87.9%
1.44 (1.38 – 1.50)
Katzmarzyk et al;. 2009
12.1%
1.51 (1.35 – 1.69)
Total
100%
1.45 (1.39 – 1.51)
0
0.5
1
1.5
2
RR (95% CI)

Figure 2.

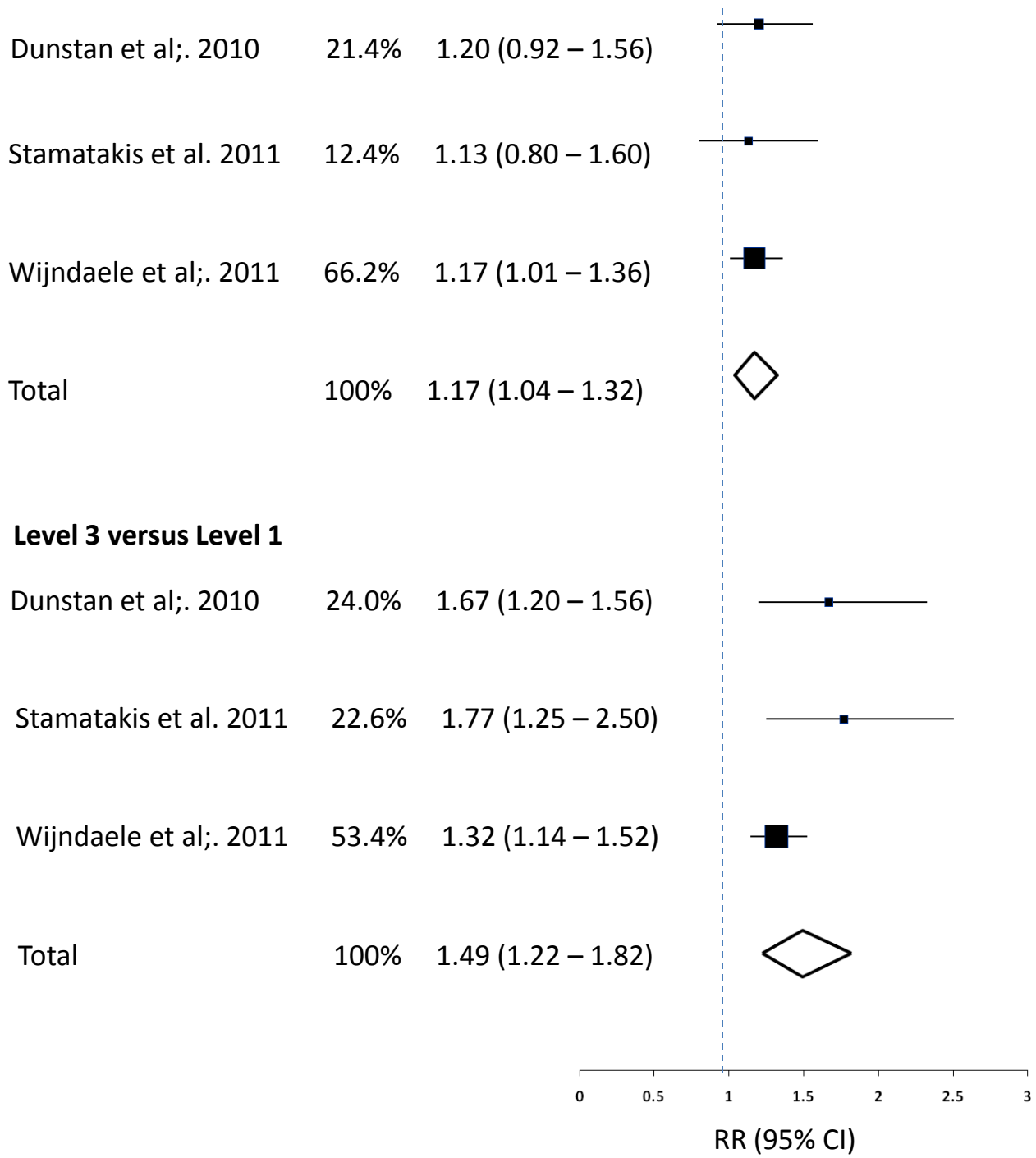
Weight
RR (95% CI)
Level 2 versus Level 1
Dunstan et al;. 2010 21.4% 1.20 (0.92 – 1.56)
Stamatakis et al. 2011 12.4% 1.13 (0.80 – 1.60)
Wijndaele et al;. 2011 66.2% 1.17 (1.01 – 1.36)
Total 100% 1.17 (1.04 – 1.32)
Level 3 versus Level 1
Dunstan et al;. 2010 24.0% 1.67 (1.20 – 1.56)
Stamatakis et al. 2011 22.6% 1.77 (1.25 – 2.50)
Wijndaele et al;. 2011 53.4% 1.32 (1.14 – 1.52)
Total 100% 1.49 (1.22 – 1.82)
0
0.5
1
1.5
2
2.5
3
RR (95% CI)

Figure 3.