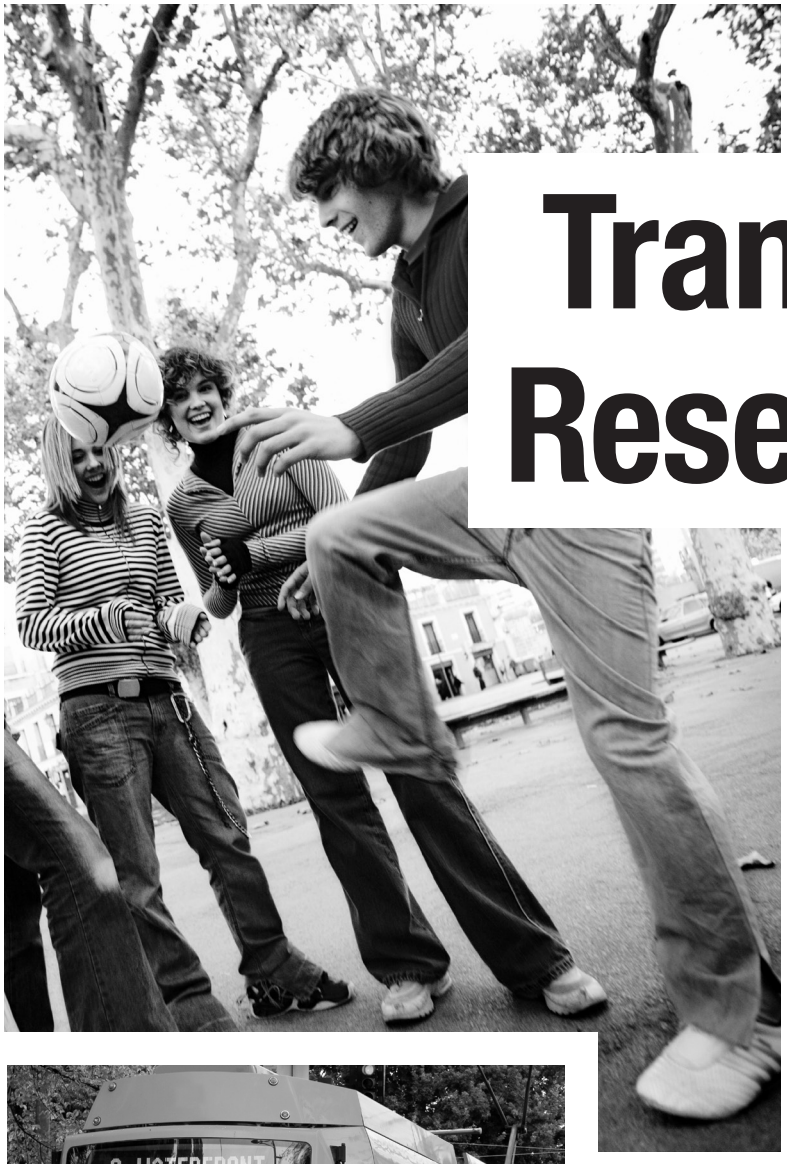

# Transportation Research Briefs


Oregon Health Authority

PUBLIC HEALTH

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Oregon Health Authority
PUBLIC HEALTH DIVISION
Health Impact Assessment Program
Center for Health Protection

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# Executive summary

Part of a series of research briefs on the health impacts of transportation options in Oregon

## Transportation and health: a summary of current research

### Transportation decisions influence the leading causes of illness and death in Oregon

The five leading causes of death in Oregon in 2010 were cancer, heart disease, lung disease, stroke and unintentional injuries (including car crashes). Unintentional injuries were the leading cause of death for Oregonians aged 1–44 years.[1] Transportation decisions can address these health concerns by reducing air pollution exposure and improving traffic safety, physical activity levels and access to community resources such as parks, schools and living wage jobs.

### Physical inactivity is dangerous for our health

Physical inactivity is associated with many common diseases, including diabetes, cardiovascular disease, breast cancer, colon cancer and dementia. Physical activity is beneficial to everyone's health regardless of weight or diet.[2] The Centers for Disease Control and Prevention (CDC) recommends at least 150 minutes per week of moderate-intensity aerobic physical activity for adults, and twice that amount for children.[3] Meeting or exceeding this recommendation is associated with a 20–30 percent reduction in the risk of premature death from all causes.[4] Compared to being inactive, meeting or exceeding the CDC's physical activity recommendation is associated with an increased life expectancy of between 3.4 and 4.5 years.[5] In 2009, approximately 45 percent of Oregonians did not meet aerobic physical activity recommendations; 18 percent of this group reported being completely sedentary.[6]

### Physical inactivity is costly for everyone

Chronic diseases aren't just deadly; they are also expensive for families and employers. According to the CDC, each year Oregon spends $411 million on asthma, $1.9 billion on cancer, $892 million on depression, $1.7 billion on diabetes, and $3.6 billion on cardiovascular diseases including stroke and hypertension. Taxpayer-funded state and federal health care programs pay for approximately 35 percent of these diseases' total cost.

### Active transportation is a promising way to increase physical activity

Physical activity levels have decreased significantly in the past several decades due to profound changes in land development patterns, car-oriented transportation systems, and many technologies that automate our lives, such as dishwashers and computers.[7] While the

CDC indicates that "more is better," meeting the recommended 30 minutes of daily activity in sessions as short as 10 minutes has major benefits.[8] Because people who walk, bike or take transit are more likely to meet physical activity recommendations, many experts believe active transportation is a highly promising way to increase physical activity.[9]

## The benefits from active transportation outweigh the risks

The risk of injury and premature death for people who bike and walk is somewhat higher than for people traveling by car or transit.[10] However, considering the combined risks of traffic crashes and exposure to pollutants, researchers have concluded that the health benefits of physical activity from active transportation greatly outweigh the risks.[11] In addition, when more people substitute active transportation for travel in cars, air pollution decreases.

## The design of the places where people drive, take transit, bike and walk matters

The design of our streets and communities directly affects the safety of people biking and walking. It also influences how often people choose active transportation. A transportation system with many safe and convenient options provides people with flexible and healthy choices to routinely shift from single-occupancy vehicles to more active modes of transportation.[12]

## Transportation health risks and benefits are unevenly distributed

Transportation infrastructure and service can vary significantly between communities. Not all Oregonians have access to healthy transportation options and health-promoting community resources. Some populations, such as people of color and older adults, bear a disproportionate burden of disease.[13] Improved transportation systems greatly alleviate the burdens on disadvantaged households.

## The bottom line

Active transportation is beneficial for health. Indeed, because transportation choices allow people to routinely and flexibly integrate physical activity into their everyday lives, active transportation represents one of our best opportunities to improve health and reduce costs to our communities.

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1 Oregon Health Authority Public Health Division. (2012). State health profile. Retrieved March 30, 2015 from https://public.health.oregon.gov/About/Documents/oregon-state-health-profile.pdf.

2 Woodcock J, Edwards P, Tonne C, Armstrong BG, Ashiru O, Roberts I, et al. (2009). Public health benefits of strategies to reduce greenhouse-gas emissions: urban land transport. The Lancet, 374(9705), 1930-1943.

3 Centers for Disease Control and Prevention. (2008). Physical activity guidelines for Americans. Retrieved March 31, 2015 from www.health.gov/paguidelines/guidelines/default.aspx.

4 Leitzmann MF, Park Y, Blair A, Ballard-Barbash R, et al. (2007). Physical activity recommendations and decreased risk of mortality. Archives of Internal Medicine, 167(22):2453-2460. doi:10.1001/archinte.167.22.2453.

5 Moore SC, Patel AV, Matthews CE, et al. (2012). Leisure time physical activity of moderate to vigorous intensity and mortality: a large pooled cohort analysis. PLOS Medicine, 9(11): e1001335. doi:10.1371/journal.pmed.1001335.

6 Winett L, Gaunter C, Becker T, Mladenovic J. (2013). The state of our health 2013: key health indicators for Oregonians. Retrieved March 31, 2015 from www.ohsu.edu/xd/education/student-services/about-us/provost/upload/State-of-Our-Health-2013-monograph.pdf.

7 Pratt M, et al. (2009). Economic interventions to promote physical activity application of the SLOTH model. American Journal of Preventative Medicine, 27(3S).

8 Centers for Disease Control and Prevention. (2011). Physical activity and health: the benefits of physical activity. Retrieved March 31, 2015 from www.cdc.gov/physicalactivity/everyone/health/index.html.

9 King AC, Sallis JF. (2009). Why and how to improve physical activity promotion: lessons from behavioral science and related fields. Preventive Medicine, 49(4), 286-288.

10 Beck LF, Dellinger AM, O'neil ME. (2007). Motor vehicle crash injury rates by mode of travel, United States: using exposure-based methods to quantify differences. American Journal of Epidemiology, 166(2), 212-218.

11 Teschke K, et. al. (2012). Bicycling: health risk or benefit? University of British Columbia Medical Journal, March 2012 3(2).

12 Miranda-Moreno LF, Morency P, El-Geneidy AM. (2011). The link between built environment, pedestrian activity and pedestrian-vehicle collision occurrence at signalized intersections. Accident Analysis and Prevention, 43(5): 1624-34. doi: 10.1016/j.aap.2011.02.005.

13 Oregon Health Authority Office of Equity and Inclusion. (2013). State of equity report. Retrieved March 31, 2015 from www.oregon.gov/oha/oei/Documents/soe-report-ph2-2013.pdf.

# Methods

Part of a series of research briefs on the health impacts of transportation options in Oregon

The briefs begin with minimally technical language in describing relationships. To justify relational statements, an accounting of the scientific and empirical literature is provided at the end of each brief in a "traceable account." The Oregon Health Authority (OHA) took a comprehensive approach to reviewing evidence. Like a systematic literature review, we scanned major databases for relevant articles using focused search terms. Unlike a systematic review, we did not create inclusion/exclusion criteria for the studies we found. Rather, we established a system of valuing evidence that categorizes studies according to their research design and confidence in findings. For example, a rigorous longitudinal study with a large sample size would be categorized as high quality evidence, whereas a white paper or case study would be considered low quality.

## Pathways and links

A critical concept in our approach is the causal pathway depicted in each brief. Health outcomes associated with transportation can have very simple causal pathways (e.g., a car crash results in death) or very complex ones (e.g., lifelong exposure to noise resulting in heart attacks). In many cases, the relationships examined in research studies are only one link on a complex pathway. For example, there are many studies on air pollution and mortality, but few on the exposure of bicyclists to air pollution. It can be difficult to draw

Table 1. **Criteria for characterizing evidence**

| | Method | Source |
|---|---|---|
| **Emerging** | Supported by case studies, public health principles and theory | Citable expert opinions, case studies, gray literature or conference proceedings |
| **Moderate** | Some observational studies or few experimental studies, mostly consistent results or modest effect sizes | Five or more peer-reviewed studies with consistent findings |
| **Strong** | Many observational studies or some experimental studies, consistent results or large effect sizes | More than five empirical studies or literature reviews |
| **Very strong** | Many observational or experimental studies, consistent results and large effect sizes | More than 10 empirical studies or literature reviews of high-integrity experimental design |

conclusions about entire pathways when evidence is segmented, so we have focused on the strength of evidence for each link of a causal pathway. Table 1 details the approach used in characterizing the evidence for each link.

Criteria such as these are inherently arbitrary, and professional judgment is occasionally necessary. For example, in some cases we characterized evidence as "weak" because of a nearly complete lack of evidence. We elevated the strength of evidence in cases of very large sample sizes, such as the U.S. Census, or in cases of authoritative recommendations from government agencies such as the Centers for Disease Control and Prevention (CDC).

## Individual vs. population effects

There is an important distinction between individual and population health. The briefs have largely focused on individual health risks and benefits associated with mode shifts, but there are significant population health impacts as well. For example, reducing total vehicle miles traveled reduces risk from air pollutants across the population. There are also external risks and benefits loops that could cause additional population-wide impacts, such as the safety in numbers effect, where biking safety improves as the number of people who bike increases.

## Potential updates

This is an area of intensely active research, and we expect the evidence to evolve rapidly. In some cases, we have noted where we expect to be able to elevate the strength of evidence within a few years based on the direction of current research. We will endeavor to update these briefs as resources are available. In addition to updating them, we hope to create briefs for related topics. These include:

- Population-level health impacts of mode shifts;
- Alternative work schedules and telecommuting;
- Car-sharing;
- Safety impacts of alcohol.

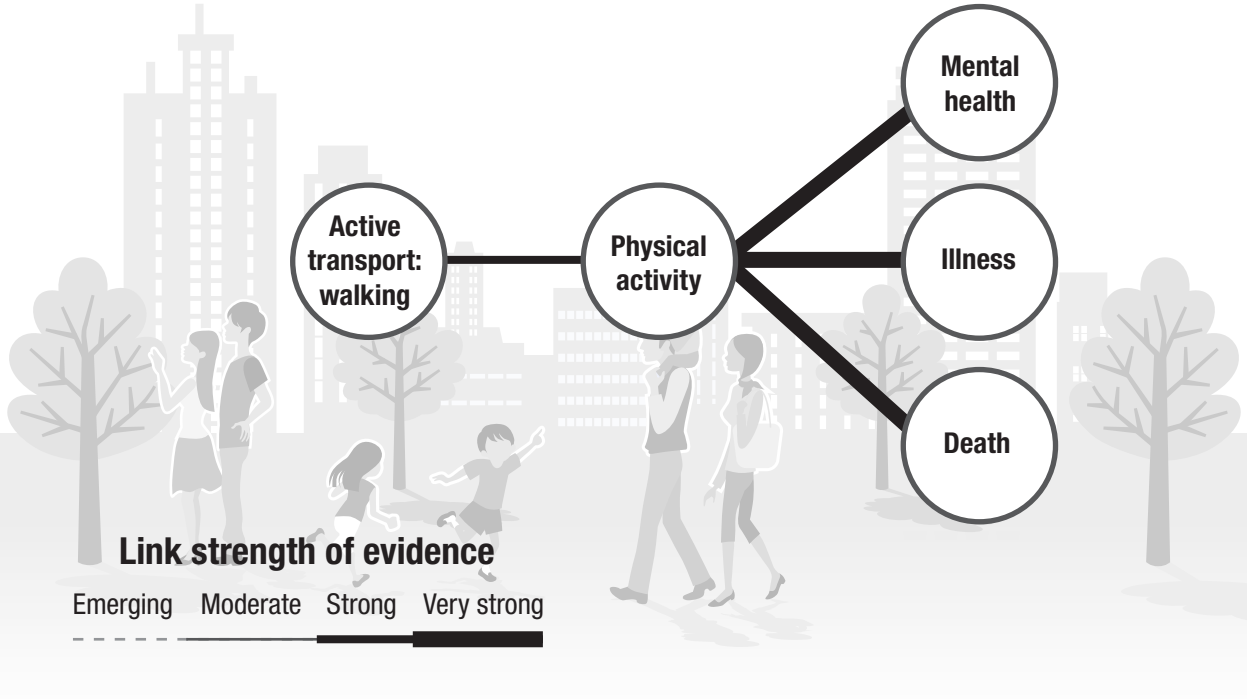
# Walking and health

Part of a series of research briefs on the health impacts of transportation options in Oregon

## Health benefits

The benefits of walking for transportation follow a pathway of relationships displayed in Figure 1. Walking for active transportation is a form of physical activity, which reduces obesity. Physical activity also has direct relationships with death and illness from chronic disease, as well as mental health.

Figure 1. **Pathway of benefits from walking for active transportation**




## Physical activity

**There is very strong evidence that physical activity is beneficial to health**. Benefits of physical activity include reduced risk of cardiovascular disease, type 2 diabetes and some cancers, especially colon and breast cancer. Additionally, physical activity reduces the risk of obesity, strengthens bones and muscles, prevents falls, and extends life expectancy.[1] Physical activity is beneficial to health regardless of weight or diet, even in small doses. The Centers for Disease Control and Prevention (CDC) recommends 150 minutes per week of moderate intensity aerobic physical activity for adults (or 75 minutes of vigorous aerobic physical activity), along with two days per week of muscle-strengthening activity such as

weightlifting or yoga.[2] Compared to being inactive, having a physical activity level at or above the recommended 150 minutes of moderate activity is associated with an increased life expectancy of 3.4–4.5 years.[3] Adherence to this recommendation is associated with a 20-30 percent reduction in the risk of death from all causes.[4] Additional physical activity beyond these recommendations results in additional health benefits, but there is evidence that the majority of health benefits are accounted for by the first 30 minutes of activity.[5] In 2013, only approximately 25 percent of Oregon adults participated in enough aerobic and muscle-strengthening exercises to meet physical activity guidelines, and approximately 19 percent reported no physical activity.[6]

**There is very strong evidence that walking for transportation is beneficial to physical health**. Walking for both recreational and utilitarian purposes is associated with an increased likelihood of meeting physical activity recommendations.[7] There is a substantial body of evidence suggesting that walking to school is beneficial for children's health and helps increase physical activity.[8] Adolescent physical activity is especially important because it is a predictor of physical activity in adulthood.[9] Experts view walking for transportation as an intervention with high potential due to its accessibility and low cost.[10] According to 2008–2012 census estimates, approximately 4 percent of Oregonians walk to work.[11] National data (2009) suggest that approximately 10 percent of all trips are made on foot, although walking is thought to be under-reported.[12]

## Mental health

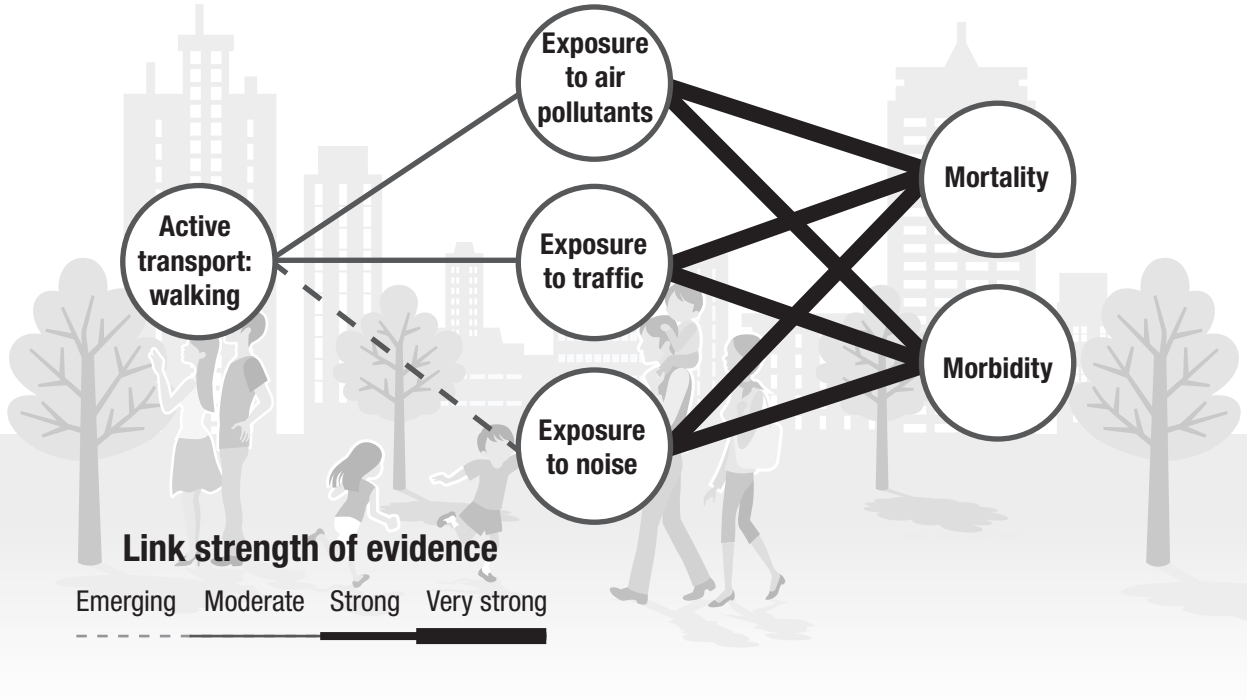
**There is very strong evidence that physical activity is beneficial to mental health**. Extensive research suggests that physical activity can reduce symptoms of depression and improve mood and self-reported wellbeing.[13] Studies have found physical activity to be an effective treatment for depression.[14] A review of available evidence found that physical activity reduces anxiety by 48 percent.[15] Mental health problems are common in Oregon; only two thirds of Oregonians report good mental health (2006–2009).[16] In 2010, Oregon had the eighth highest suicide rate in the United States.[17]

**There is moderate evidence that walking for transportation is beneficial to mental health**. Research strongly suggests an association between physical activity and mental health. However, when looking only at active transportation, some studies found benefits to physical health but failed to find significant mental health benefits.[18] Some studies have found that commuting to work by any mode is a source of unhappiness,[19] and there is some evidence that walking and biking are less stressful than commuting by car or transit.[20, 21]

## Risks

**There is very strong evidence that physical activity is beneficial to mental health**. Risks from walking for transportation are outlined in the pathway diagram below (Figure 2). Walking for active transportation can lead to exposure to risks from pollutants, traffic crashes and noise.

Figure 2. **Pathway of risks from walking for active transportation**




## Injuries

**There is moderate evidence that, compared to other travel modes, the risk of injury from walking is high**. The rate of fatal injuries per person trip is significantly higher for walking compared to traveling by bus or passenger vehicle, and pedestrians are 1.5 times as likely to be killed on any trip as those traveling by bus or car are.[22] The highest death rates are among older adults, a population expected to increase in coming years.[23] Nationwide, pedestrians account for 12 percent of traffic crash fatalities, but make up just 9 percent of trips.[24] Approximately 18 percent of all traffic deaths in Oregon in 2012 were to pedestrians.[25] As in all traffic crashes, alcohol is often a contributing factor to pedestrian crashes resulting in injuries and deaths.

**There is strong evidence that environmental factors contribute to pedestrian risk**. A wide range of environmental and demographic factors has been associated with risk of injury among pedestrians.[26] Research consistently finds environmental factors such as lighting, the number of intersections in an environment, residential density, land use and traffic volume to influence risk. One study estimated a 35 percent decrease in injuries would result from a 30 percent decrease in traffic volume.[27]

### Air pollution

**There is very strong evidence that pollution from traffic is harmful to health**. Many observational and experimental studies have shown negative impacts from automobile emissions, including respiratory illness, cardiovascular disease and cancer.[28, 29, 30] One recent study estimated that air pollution from transportation rivals traffic crashes as a cause of death.[31] In 2011, Oregon had the sixth highest percentage of adults with asthma among U.S. states, and asthma hospitalizations in the state cost more than $28 million.[32]

**There is moderate evidence that people traveling on foot are disproportionately exposed to harmful air pollutants**. All roadway users are exposed to harmful air pollutants, but some evidence suggests that pedestrians are disproportionately exposed.[33] Researchers suggest that the variation in exposure based on traffic, meteorological factors such as the effect of wind, route and other factors make it difficult to accurately determine whether people traveling on foot are at greater danger from pollution.[34] More research is needed to improve our understanding of risks to pedestrians.

### Noise

**There is very strong evidence that road noise is harmful to health**.[35] Road noise is associated with sleep problems, high blood pressure, difficulty concentrating and learning, hearing loss and heart attacks.[36,37] The effects of various kinds of noise on children are poorly understood.[38]

**There is weak evidence that road noise disproportionately affects people walking**. Few studies investigate traffic noise exposure by mode. An eight-hour exposure to the level of noise expected from a busy road can harm hearing and induce high levels of annoyance, in addition to other health problems.[39] This suggests that health effects of noise may be avoided on streets with low traffic volumes.

## Conclusions

**Shifting from vehicle travel to walking is likely to be beneficial for health**. The protective effects of physical activity from walking for transportation include reduced cardiovascular disease, cancer, obesity, diabetes, symptoms of depression, and other positive health impacts. These benefits greatly outweigh increases in exposure to traffic crashes and air pollution.

**The health benefits of walking outweigh the risks**. Evidence on the critical role of physical activity in maintaining health is unequivocal. Risks can be reduced by behavioral and environmental factors.

**Some groups benefit from physical activity more than others do**. Researchers point out that the benefits of physical activity, particularly to mental health, may not be as great when travel by active modes is imposed rather than chosen. Studies have found that the relationship between body weight and active transportation is stronger among whites than among people of color.

# Traceable accounts

Traceable accounts provide a summary of evidence reviewed for each of the associations and findings made above.

| Physical activity | Walking |
|---|---|
| **There is very strong evidence that walking for transportation is beneficial to physical health.** | |
| **Description of evidence base** | We reviewed 39 studies suggesting an association between walking and physical activity. Most were observational or cross-sectional. Many studies on active transportation to school among students suggest that walking to school helps achieve physical activity recommendations. Although experimental studies were few, the large number and consistent findings of the many observational studies we reviewed overcome study limitations. After accounting for the risk of bias, chance and confounding, we conclude that walking is beneficial to health. |
| **Remaining uncertainties** | Further research is necessary to clarify whether physical activity from walking for transportation displaces other physical activity. It is conceivable that switching from a sedentary transportation mode to an active one could result in no net gain or negative change in physical activity if the person switching simultaneously reduces leisure time physical activity. However, multiple studies explore the complexity of this relationship, showing no displacement for youth and particularly among boys. Some evidence associates shorter commute times with more physical activity, and some evidence associates active commuting with leisure time physical activity. One study found that considering active transportation as physical activity increases the estimated prevalence of adherence to recommendations.<br><br>Further research is needed to understand the effect of walking on sub-populations.<br><br>There also remains uncertainty about the types of built environment that are more effective in increasing walking and, therefore, increasing physical activity. |
| **Assessment of confidence** | Very strong |

| Evidence reviewed: physical activity | | | Walking |
|---|---|---|---|
| **Quality** | **Description** | **Count** | **Reference list** |
| High | Longitudinal/controlled experimental study | 3 | Booth2014, Hu2005, Wanner2014 |
| High | Systematic review/meta-analysis | 9 | Durand2011, Gunther2011, Hamer2008, Johnson2013, Larouche2014, Lee2008, Rauner2013, Saunders2013, Wanner2012 |
| Medium | Observational/cross-sectional | 17 | Berrigan2006, Boone-Heinonen2009, Brit2007, Brockman2011, Brown2013, Buehler2011, Cooper2005, Gordon-Larsen2005, Hirsch2013, Hu2002, Hu2003, Humphreys2013, Pucher2010, Mendoza2011, Millett2013, Sirard2008 |
| Medium | Quantitative modeling | 3 | Maizlish2013, Rabl2012, Woodcock2014 |
| Medium | Literature review | 6 | deNazelle2011, Faulkner2009, Frank2001, Handy2014, Litman2013, Lubans2011 |
| Low | Case studies or small sample size | 1 | Borrestad2013 |
| Low | Expert opinion, best practice, gray literature | | |

| Physical activity – morbidity and mortality | | Walking |
|---|---|---|
| **There is very strong evidence that physical activity is beneficial to individual health.** | | |
| **Description of evidence base** | There is near scientific consensus that physical activity has a causal relationship with morbidity and mortality. The CDC cites a vast body of evidence showing that physical activity reduces risk of type 2 diabetes, cardiovascular disease and cancer, which are among the leading causes of death. Physical activity also appears to moderate stress, reducing stress-related illness. Physical activity also appears to have a prescriptive effect in lowering the risk of death for those already diagnosed with diabetes or heart disease. | |

| | |
|---|---|
| | We reviewed more than 58 studies that consistently demonstrate this relationship. Evidence linking physical activity with morbidity and mortality is high quality, often from longitudinal experiments. We are very confident in this conclusion. |
| **Remaining uncertainties** | The nature of the dose-response relationship between physical activity and illness/death is not fully understood. Evidence clearly shows that some physical activity is better than no physical activity, and that adding activity provides more benefits. However, the rate at which benefits accrue, particularly by activity-type and intensity, is uncertain. |
| **Assessment of confidence** | Very strong |

| **Evidence reviewed: physical activity – morbidity and mortality** | | | **Walking** |
|---|---|---|---|
| **Quality** | **Description** | **Count** | **Reference list** |
| High | Longitudinal/controlled experimental study | 17 | Anderson2000, Arem2013, Barlow2013, Belavia2013, Ekelund2013, Hu2005, Lee2010, Luoto2000, Je2013, Moe2013, Menschik2008, Shmid2014, Shortreed2013, Wanner2014, Wen2014, Zhao2014, Zhou2014 |
| High | Systematic review/meta-analysis | 20 | Fogelholm2010, Goncalves2014, Guenther2011, Guh2009, Hamer2008, Kruk2007, Lee2001, Johnson2013, Loprinzi2014, Moore2012, Nocan2008, Oja2011, Pucher2010, Rauner2013, Reiner2013, Saunders2013, Schmitz2005, Stephens2014, Wanner2012, Woodcock2011 |
| Medium | Observational/cross-sectional | 7 | Brown2013, Hu2003, Gordon-Larsen2005, Leitzmann2007, Mendoza2011, Millett2013, Ming2008 |
| Medium | Quantitative modeling | 3 | Kahlmeier2010, MacMillan2014, Maizlish2013 |

| Evidence reviewed: physical activity – morbidity and mortality *(continued)* | | | Walking |
|---|---|---|---|
| **Quality** | **Description** | **Count** | **Reference list** |
| Medium | Literature review | 11 | de Rezende2014, Demark-Wahnefried2014, Gerber2009, Haskell2009, Litman2013, Lovasi2009, Lubans2011, McMillan2009, Nelson2007, Powell2011, Wareham2005 |
| Low | Case studies or small sample size | | |
| Low | Expert opinion, best practice, gray literature | | |

| Physical activity – mental health | | Walking |
|---|---|---|
| **There is very strong evidence that physical activity is beneficial to mental health.** | | |
| **Description of evidence base** | We reviewed 23 studies linking physical activity and mental health, all with consistent findings. Evidence supports an association between physical activity and mental health across the life course (childhood to old age). The CDC notes that regular physical activity can help maintain thinking, learning and judgment into old age, and that it also reduces symptoms of depression. The literature supports physical activity as both a preventive measure and an intervention for mental health. It also notes the mediating role physical activity and mental health play in recovery from disease such as cardiovascular events or cancer. | |
| **Remaining uncertainties** | The nature of the relationship between physical activity, active transportation and mental health is less certain. Much of the literature on physical activity and mental health focuses on leisure time physical activity or co-mingles leisure and non-leisure physical activity. Some investigators have noted that the mental health benefits of active transportation may vary by socioeconomic status, or might be less if active transportation is imposed rather than chosen. It is, therefore, difficult to state with confidence that active transportation universally leads to mental health benefits despite the clear association between physical activity and mental health. | |
| **Assessment of confidence** | Very strong | |

| Evidence reviewed: physical activity – mental health | | | Walking |
|---|---|---|---|
| **Quality** | **Description** | **Count** | **Reference list** |
| High | Longitudinal/controlled experimental study | | |
| High | Systematic review/meta-analysis | 8 | Ahn2011, Biddle2011, Brown2013, Daley2008, Krogh2011, Mammen2013, Reiner2013, Tremblay2011 |
| Medium | Observational/cross-sectional | 4 | Asztalos2009, Humphreys2013, Olsson2013, Scarapicchia2014, Wener2011 |
| Medium | Literature review | 7 | Coon2014, Hammer2012, Johnson2011, Mason2012, Teychenne2008, Teychenne2010, Tomporowski2011 |
| Medium | Quantitative modeling | | |
| Low | Case studies or small sample size | 4 | Fox2007, Gatersleben2007, LaJeunesse2012, Rubens2013 |
| Low | Expert opinion, best practice, gray literature | | |

| Physical activity – traffic injuries | | Walking |
|---|---|---|
| **There is moderate evidence that, compared to other travel modes, the risk of injury from walking is high.** | | |
| **Description of evidence base** | There are reliable estimates of injury rates among people traveling on foot, but studies with comparable exposure-based injury rates across modes are few. We found only one study that provides injury and fatality rates based on exposure in person-trips and another based upon exposure based on miles traveled. Many studies focus on the conditions surrounding pedestrian injuries, especially environmental variables, finding numerous associations. Considering this mix of findings, we conclude that there is a moderate strength of evidence supporting the association between walking and elevated traffic injury rates. | |

| Physical activity – traffic injuries *(continued)* | Walking |
|---|---|
| **There is moderate evidence that, compared to other travel modes, the risk of injury from walking is high.** | |
| **Remaining uncertainties** | There are clear mitigating factors that reduce injuries, such as the presence of separated sidewalks and crossings, vehicle speed, and other contextual factors. This makes drawing conclusions difficult. Further complicating conclusions is the so-called "safety in numbers" effect that has been observed in many cities. Whereas there is a clear correlation between greater numbers of pedestrians and lower injury rates, the causal mechanism for this correlation is poorly understood.<br><br>Studies of pedestrian injuries and fatalities are strengthened by relatively comprehensive records of severe injuries and deaths, but are hampered by scarce data on exposure. That is to say, counts of pedestrian traffic in areas with crash data are rare. Without measures of exposure, characterizing risk is inherently difficult. |
| **Assessment of confidence** | Moderate |

| Evidence reviewed: traffic injuries | | | Walking |
|---|---|---|---|
| **Quality** | **Description** | **Count** | **Reference list** |
| High | Longitudinal/controlled experimental study | 1 | Beck2007 |
| High | Systematic review | 2 | Wong2011, Rothman2014b |
| Medium | Observational/cross-sectional | 8 | Blaizot2013, Bunn2003, Jacobsen2003, Jones2005, Koepsell2002, Lovasi2013, Mader2014, Rothman2014a |
| Medium | Quantitative modeling | 5 | Maizlish2013, Rabl2012, Wei2012, Wier2009, Woodcock2009 |
| Medium | Literature review | 4 | deNazelle2011, Jacobsen2009, Lovasi2009, Retting2003 |
| Low | Case studies or small sample size | | |
| Low | Expert opinion, best practice, gray literature | 2 | Bhatia2011 |

| Exposure to pollutants | Walking |
|---|---|
| **There is moderate evidence that people traveling on foot are disproportionately exposed to harmful air pollutants.** | |
| **Description of evidence base** | We reviewed 15 studies on pedestrian exposure to air pollution. The mix of findings causes us to rate the strength of evidence as moderate. Whereas several studies show that pedestrians are exposed to high levels of vehicle emissions, many studies show that vehicle passengers are also exposed to high levels of emissions. Contextual factors make it difficult to form broad conclusions comparing one mode of travel to another. |
| **Remaining uncertainties** | There is significant uncertainty as to how pedestrian exposure compares to other modes. Contextual factors of the microenvironment such as weather, wind, traffic flow, time of day and route choice all appear to influence exposure; this is further complicated by personal dosage as a function of uptake and duration. |
| **Assessment of confidence** | Moderate |

| Evidence reviewed: exposure to pollutants | | | Walking |
|---|---|---|---|
| **Quality** | **Description** | **Count** | **Reference list** |
| High | Longitudinal/controlled experimental study | 1 | Kaur2009 |
| High | Systematic review | 1 | Knibbs2011 |
| Medium | Observational/cross-sectional | 6 | Briggs2008, de Nazelle2012, Dons2012, Dons2013, Morabia2009, Nyhan2013 |
| Medium | Quantitative modeling | 4 | de Nazelle2009, Gordon2012, Maizlish2013, Rabl2012 |
| Medium | Literature review | 1 | Giles2014 |
| Low | Case studies or small sample size | 1 | Gulliver2004 |
| Low | Expert opinion, best practice, gray literature | 1 | Figliozzi2012 |

| Exposure to pollutants – morbidity and mortality | Walking |
|---|---|
| **There is very strong evidence that pollution from transportation sources is harmful to health.** | |
| **Description of evidence base** | We reviewed 49 studies suggesting that transportation emissions harm health. These studies show consistent results and large effect sizes, and many have high-quality longitudinal or experimental designs. Major scientific agencies – including the Centers for Disease Control and Prevention, Environmental Protection Agency, the World Health Organization and the American Heart Association –conclude a causal relationship exists between auto emissions and health. |
| **Remaining uncertainties** | We know that, broadly speaking, vehicle pollutants are harmful to health and that distance to high-traffic areas is a significant health risk. We have less information about acute exposures by different travel modes due to uncertainty about microenvironments. There also remains uncertainty about mechanisms by which air pollution harms health including which pollutant(s) result in specific health outcomes. |
| **Assessment of confidence** | Very strong |

| Evidence reviewed: exposure to pollutants – morbidity and mortality | | | Walking |
|---|---|---|---|
| **Quality** | **Description** | **Count** | **Reference list** |
| High | Longitudinal/controlled experimental study/ attributable fraction | 18 | Baleen2014a, Baleen2014b, Brunekreef2009, Chen2013, Dimakopoulou2014, Caiazzo2013, Gan2012, Gauderman2004, Hart2013, Hennig2014, Hoffmann2005, Hoffmann2007, Hoffmann2009a, Kälsch2014, Lepeule2012, Pope2009, Sørensen2012, Vineis2007 |
| High | Systematic review/meta-analysis | 6 | Brook2010, Chen2008, Janssen2011, Meng2013, WHO2003, WHO2013 |

| | | | |
|---|---|---|---|
| Medium | Observational/cross-sectional | 15 | Fuks2011, Hoffman2006, Hoffmann2009b, Kim2008, Lui2014, McConnell2006, McCreanor2007, Morabia2009, Nwokoro2012, Peters2013, Spira-Cohen2011, Strak2010, vanKempen2012b, Weichenthal2011, Zuurbier2010 |
| Medium | Quantitative modeling | 4 | MacMillan2014, Maizlish2013, Xia2013, Zhang2013 |
| Medium | Literature review | 5 | Brugge2007, Gold2013, Hofmann2011, Kelishadi2011, Laumbach2010 |
| Low | Case studies or small sample size | | |
| Low | Expert opinion, best practice, gray literature | 1 | Forastiere2013 |

| **Noise** | **Walking** |
|---|---|
| **There is weak evidence that traffic noise disproportionately affects pedestrians.** | |
| **Description of evidence base** | Traffic noise is associated with negative health outcomes (see below). Expert opinion and theory posit a relationship, but there is essentially no evidence. One study examined differences in noise between car travel and bicycling, but findings were mixed and do not offer a strong basis for conclusions about exposure while walking. |
| **Remaining uncertainties** | There is very little research that walking and exposure to noise are linked. Traffic noise studies typically focus on long-term (8 hours or more) exposure to traffic noise, rather than the episodic exposure that could be expected with active transportation. |
| **Assessment of confidence** | Weak |

| Evidence reviewed: noise | | | Walking |
|---|---|---|---|
| **Quality** | **Description** | **Count** | **Reference list** |
| High | Longitudinal/controlled experimental study | | |
| High | Systematic review | | |
| Medium | Observational/cross-sectional | 1 | Boogaard2009 |
| Medium | Quantitative modeling | | |
| Low | Case studies or small sample size | | |
| Low | Expert opinion, best practice, gray literature | | |

| Noise – morbidity and mortality | | Walking |
|---|---|---|
| **There is very strong evidence that traffic noise is harmful to health.** | | |
| **Description of evidence base** | We reviewed 43 studies linking morbidity and mortality to traffic noise exposure. These studies had consistent results and moderate effect sizes that seem to hold even when controlling for air pollution exposure. One of the strongest associations was between noise and myocardial infarction and/or hypertension with additional evidence of risk of diabetes and negative cognitive consequences for children. The literature draws heavily from residential exposure, implying long-term exposure particularly at night. | |
| **Remaining uncertainties** | Most noise studies are not specific to active transportation and many are from long-term rather than short-term exposure, making it difficult to generalize.<br>Noise and air pollution are highly correlated. While Gan2012, Kalsch2014, Sørensen2012 and other studies suggest independent effects, future research is needed to understand the confounding relationship.<br>One branch of the traffic noise literature clearly describes annoyance as a result of exposure to traffic exposure. Annoyance seems to heighten negative health effects, likely through stress response, but the link between annoyance and other health outcomes could be more solid.<br>Threshold and dose-response are starting to be reported, but additional research is needed to fine-tune each. | |
| **Assessment of confidence** | Strong | |

| Evidence reviewed: noise – morbidity and mortality | | | Walking |
|---|---|---|---|
| **Quality** | **Description** | **Count** | **Reference list** |
| High | Longitudinal/controlled experimental study | 8 | Kälsch2014, Gan2012, Hart2013, Notbohm2013, Sørensen2011, Sørensen2012, Sørensen2013, Sørensen2014 |
| High | Systematic review/meta-analysis | 7 | Babisch2008, Babisch2014, Ndrepepa2011, Tetreault2013, Tomei2010, vanKempen2012a, WHO2011 |
| Medium | Observational/cross-sectional | 13 | Babisch2013, Banerjee2013, Birk2011, Chang2014, de Kluizenaar2013, Floud2013, Foraster2011, Fuks2011, Haralabidis2011, Liu2013, Liu2014, Huang2013, Kraus2013 |
| Medium | Literature review | 11 | Basner2014, Davies2012, Goins2007, Hammer2014, Kelishadi2011, Muenzel2014, Muzet2007, Pirrera2010, Seidman2010, vanCamp2013, vanKempen2012b |
| Medium | Quantitative modeling | 1 | Harding2013 |
| Low | Case studies or small sample size | | |
| Low | Expert opinion, best practice, gray literature | 3 | Kairns2014, Foraster2013, Holzman2014 |

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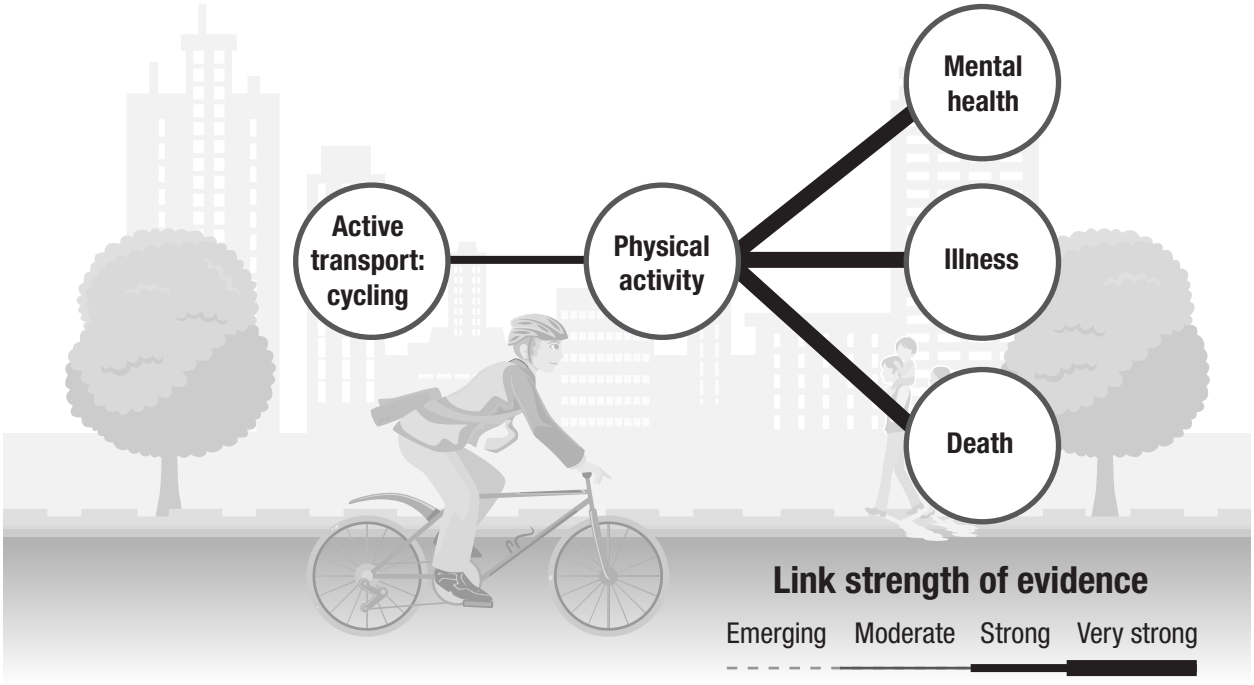
# Bicycling and health

Part of a series of research briefs on the health impacts of transportation options in Oregon

## Health benefits

The benefits of bicycling for transportation follow a pathway of relationships displayed in Figure 1. Bicycling for active transportation is a form of physical activity that reduces obesity. Lack of physical activity also has direct relationships with death and illness from chronic disease, as well as mental health.

Figure 1. **Pathway of benefits from bicycling for active transportation**




## Physical activity

**There is very strong evidence that physical activity is beneficial to health**. Benefits of physical activity include reduced risk of cardiovascular disease, type 2 diabetes and some cancers, especially colon and breast cancer. Additionally, physical activity reduces the risk of obesity, strengthens bones and muscles, prevents falls, and extends life expectancy.[1] Physical activity is beneficial to health regardless of weight or diet, even in small doses.[2]

The CDC recommends 150 minutes per week of moderate intensity physical activity for adults (or 75 minutes of vigorous physical activity), along with two days per week of muscle-strengthening activity such as weightlifting or yoga.[2] Compared to being inactive,

having a physical activity level at or above the recommended 150 minutes of moderate activity is associated with an increased life expectancy of between 3.4 and 4.5 years.[3] Adherence to this recommendation is associated with a 20–30 percent reduction in the risk of death from all causes.[4] Additional physical activity beyond these recommendations results in additional health benefits, but there is evidence that the majority of health benefits are accounted for by the first 30 minutes of activity.[5] In 2013, approximately 25 percent of Oregon adults participated in enough aerobic and muscle-strengthening exercises to meet physical activity guidelines, and approximately 19 percent reported no physical activity.[6]

**There is strong evidence that bicycling for transportation is beneficial to physical health**. As a form of physical activity, bicycling for any purpose helps achieve physical activity recommendations.[7] Bicycling for transportation increases the likelihood of meeting recommendations.[8] One study found an approximate 40 percent decreased risk of premature mortality among those who bicycle to work compared to sedentary populations.[9] A Portland study found that 59 percent of participants achieved the recommended 150 minutes of physical activity during a week of cycling, primarily through transportation (as opposed to recreation).[10] According to 2008–2012 census estimates, approximately 2 percent of Oregonians bicycle to work.[11]

## Mental health

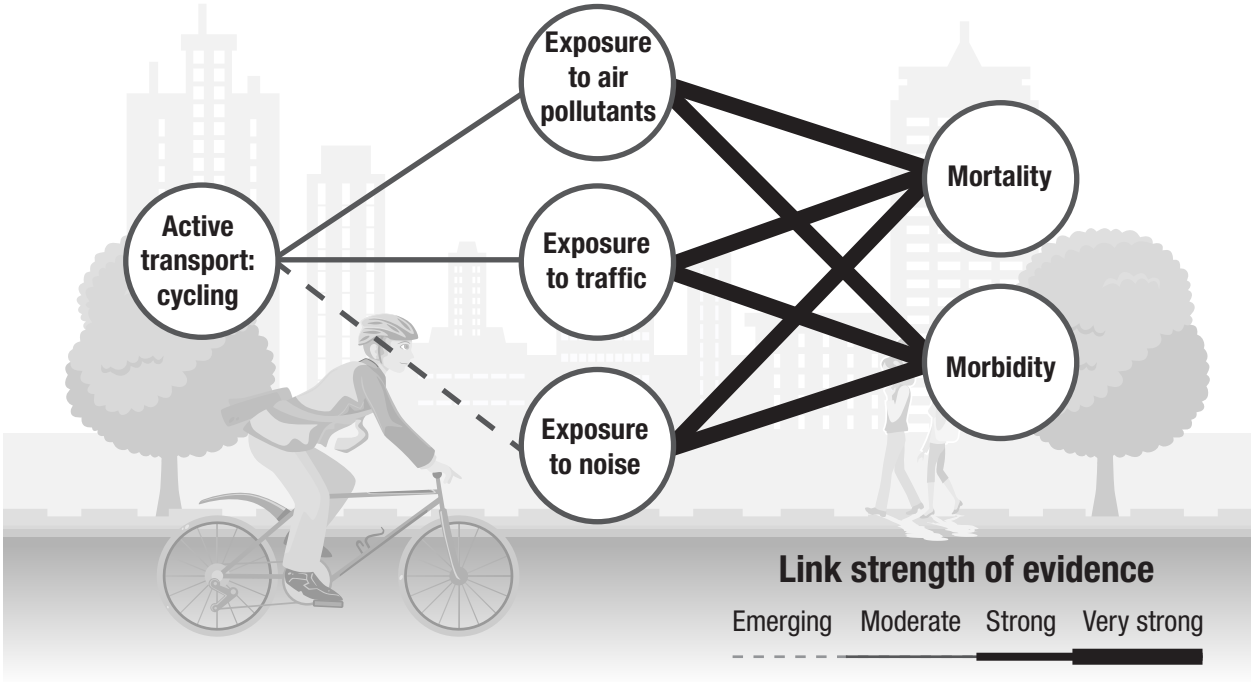
**There is very strong evidence that physical activity benefits mental health**. Extensive research suggests that physical activity can reduce depression symptoms and improve mood and self-reported well-being.[12] Studies have found physical activity to be an effective depression treatment.[13] Two-thirds of Oregonians report good mental health (2006–2009).[14] However, in 2010, Oregon's suicide rate was in the top 10 among U.S. states.[15]

**There is moderate evidence that bicycling for transportation benefits mental health**. Associations between physical activity and mental health are well established, but the evidence associating active transportation or active commuting with mental health is less clear. Several studies that have found benefits to physical health have failed to find significant mental health benefits.[16] Although some studies have found that commuting is a source of unhappiness, there is some evidence that walking and biking are less stressful than commuting by car or transit.[18,19]

## Health risks

Risks from bicycling for transportation are outlined in Figure 2. Bicycling for active transportation can lead to exposure to risks from pollutants, traffic crashes and noise.

Figure 2. **Pathway of risks from bicycling for active transportation**




## Injuries

**There is moderate evidence that, when compared to other travel modes, the risk of injury from bicycling is high**. In the United States, the rate of fatal injuries per person trip is significantly higher for bicycling compared to traveling by foot, bus and passenger vehicle. The fatality rate for people on bicycles is more than twice that of people in passenger cars. Whereas bicycle trips account for just 0.8 percent of trips, they represent approximately 1.6 percent of fatal injuries. Males are much more likely to suffer fatal injuries than females.[20] According to one study, the fatal injury rate for female cyclists is similar to that of females traveling in passenger vehicles.[21] Ten cyclists, or approximately 3 percent of all traffic fatalities, were killed in Oregon in 2012.[22]

**There is moderate evidence that risks can be mitigated by environmental factors**. Several studies have found lower injury rates on streets with bicycle facilities such as barriers between bicyclists and drivers.[23] Injury rates are also lower on local streets, streets with lower speeds and streets with traffic calming measures such as traffic diverters.[24]

### Air pollution

**There is very strong evidence that pollution from transportation sources is harmful to health**. Many observational and experimental studies have shown negative impacts from emissions, including respiratory illness, cardiovascular disease and cancer.[25,26,27] One recent study estimated that air pollution from transportation rivals traffic crashes as a cause of death.[28] In 2011, Oregon had the sixth highest percentage of adults with asthma among U.S. states, and asthma hospitalizations in the state cost more than $28 million.[29]

**There is moderate evidence that people traveling by bicycle are disproportionately exposed to harmful air pollutants**. All roadway users are exposed to harmful air pollutants, but studies have found consistent evidence that people on bicycles are exposed to a higher concentration of some pollutants, especially small particulate matter. Several studies have also found that people on bicycles have a higher uptake of some pollutants than their counterparts traveling by other modes have.[30,31] However, it appears that exposure depends on route choice and time of day. This suggests that separating bike routes from high emissions corridors and encouraging off-peak trips could reduce exposure to harmful air pollutants.[32] More research is needed to improve our understanding of this relationship, especially links between exposure while biking and specific health outcomes.

### Noise

**There is very strong evidence that traffic noise is harmful to health**. Traffic noise is associated with sleep problems and cardiovascular effects such as high blood pressure and heart attacks in adults, as well as difficulty concentrating and learning — particularly for children.[33,34]

**There is weak evidence that traffic noise disproportionately affects people traveling by bicycle**. Very few studies examine the traffic noise experienced by bicyclists; most traffic noise research is related to the long-term effects of traffic noise on people in their homes. Although bicycle riders are likely exposed to greater levels of noise, it is unclear whether the noise is typically loud enough or lasts long enough to have negative health effects. Further, any such relationship would heavily depend on route choice.

## Conclusions

**Shifting from vehicle travel to bicycling is likely to benefit health**. The protective effects of physical activity from bicycling for transportation include reduced cardiovascular disease, cancer, obesity, diabetes, depression symptoms as well as other positive health impacts. These benefits greatly outweigh increases in exposure to traffic crashes, air pollution and noise.

**The health benefits of bicycling far outweigh the risks**. The benefits of regular physical activity greatly outweigh the heightened risk of injury and increased exposure to pollutants and noise.[35] A study that attempted to quantify this difference found that shifting from

car to bicycle would, on average, result in a life expectancy gain of between three and 14 months. However, the increased risk from air pollution tallied between 0.8 and 40 days of life expectancy lost. The increase in injuries results in between five and nine days lost. The benefits from physical activity were nine to 16 times greater than the risk of injury, and 10 to 113 times greater than the risk from pollution.[36]

## Traceable accounts

Traceable accounts provide a summary of evidence reviewed for each of the associations and findings made above.

| **Physical activity** | **Bicycling** |
|---|---|
| **There is strong evidence that bicycling for transportation is beneficial to physical health.** | |
| **Description of evidence base** | We reviewed 46 studies suggesting an association between cycling and physical activity. The studies were all either neutral or in the expected direction of cycling increasing physical activity. Most were observational or cross-sectional. Some studies employed models to estimate that the physical activity benefits of bicycling far outweigh the risks. A large literature base devoted to youth programs through active transportation to school shows with moderate certainly that bicycling increases cardiovascular health in youth. Although experimental studies were few, the large number and consistent findings of the many observational studies we reviewed overcome study limitations. After accounting for the risk of bias, chance and confounding, we conclude that bicycling is beneficial to health.<br><br>We classified this link between bicycling and physical health as strong instead of very strong due to remaining uncertainties (see below). However, the trajectory of this body of inquiry is growing quickly and we anticipate that the categorization of evidence for physical activity will increase to very strong within the next five years. |

| Physical activity *(continued)* | Bicycling |
|---|---|
| **Remaining uncertainties** | Further research is necessary to clarify whether physical activity from bicycling for transportation displaces other physical activity. It is conceivable that switching from a sedentary transportation mode to an active one could result in no net gain or negative change in physical activity if the person switching simultaneously reduces leisure time physical activity. However, multiple studies explore the complexity of this relationship, showing no displacement for youth and particularly among boys. There is some evidence that shorter commute times are associated with more physical activity and that active commuting is associated with leisure time physical activity. One study found that considering active transportation as physical activity increases the estimated prevalence of adherence to recommendations.<br><br>Further research is needed to understand the effect of bicycling on subpopulations. Current research shows that benefits of cycling hold for males but are less certain for females.<br><br>There also remains uncertainty about the types of built environment that are more effective in increasing cycling and thus physical activity. |
| **Assessment of confidence** | Strong |

| Evidence reviewed: physical activity | | | Bicycling |
|---|---|---|---|
| **Quality** | **Description** | **Count** | **Reference list** |
| High | Longitudinal/controlled experimental study | 5 | Anderson2000, Cooper2008, Hu2005, Menschik2008, Wanner2014 |
| High | Systematic review/meta-analysis | 11 | De Hartog2010, Gunther2011, Hamer2008, Larouche2014, Lee2008, Johnson2013, Pucher2010, Oja2011, Rauner2013, Saunders2013, Wanner2012 |
| Medium | Observational/cross-sectional | 13 | Berrigan2006, Boone-Heinonen2009, Buehler2011, Cooper 2005, Gordon-Larsen2005, Heesch2014, Hu2002, Hu2003, Humphreys2013, Mendoza2011, Millett2013, Ming2008 |

| Evidence reviewed: physical activity *(continued)* | | | Bicycling |
|---|---|---|---|
| **Quality** | **Description** | **Count** | **Reference list** |
| Medium | Quantitative modeling | 8 | Graeme2011, MacMillan2014, Maizlish2013, Rabl2012, Rojas-Rueda2011, Rutter2013, Woodcock2014 |
| Medium | Literature review | 7 | deNazelle2011, Faulkner2009, Fraser2011, Frank2001, Handy2014, Litman2013, Lubans2011 |
| Low | Case studies or small sample size | 2 | Dill2009, Borrestad2013 |
| Low | Expert opinion, best practice, gray literature | | |

| Morbidity and mortality | | Bicycling |
|---|---|---|
| **There is very strong evidence that physical activity is beneficial to individual health.** | | |
| **Description of evidence base** | There is near scientific consensus that physical activity has a causal relationship with morbidity and mortality. The CDC cites a vast body of evidence showing that physical activity reduces risk of type 2 diabetes, cardiovascular disease and cancer; these diseases are among the leading causes of death. Physical activity also appears to moderate stress, reducing stress-related illness. Physical activity also appears to have a prescriptive effect in lowering the risk of death for those already diagnosed with diabetes or heart disease.<br><br>We reviewed more than 57 studies that consistently demonstrate this relationship. Evidence linking physical activity with morbidity and mortality is high quality, often from longitudinal experiments. We are very confident in this conclusion. | |
| **Remaining uncertainties** | The nature of the dose-response relationship between physical activity and illness/death is not fully understood. Evidence clearly shows that some physical activity is better than no physical activity, and that there are more benefits from additional activity. However, the rate at which benefits accrue, particularly by activity-type and intensity, is uncertain. | |
| **Assessment of confidence** | Very strong | |

| Evidence reviewed: physical activity – morbidity and mortality | | | Bicycling |
|---|---|---|---|
| **Quality** | **Description** | **Count** | **Reference list** |
| High | Longitudinal/controlled experimental study | 17 | Anderson2000, Arem2013, Barlow2013, Belavia2013, Ekelund2013, Hu2005, Lee2010, Luoto2000, Je2013, Moe2013, Menschik2008, Shmid2014, Shortreed2013, Wanner2014, Wen2014, Zhao2014, Zhou2014 |
| High | Systematic review/meta-analysis | 19 | Fogelholm2010, Goncalves2014, Guenther2011, Guh2009, Lee2001, Johnson2013, Kruk2007, Loprinzi2014, Moore2012, Nocan2008, Oja2011, Pucher2010, Rauner2013, Reiner2013, Saunders2013, Schmitz2005, Stephens2014, Wanner2012, Woodcock2011 |
| Medium | Observational/cross-sectional | 7 | Brown2013, Hu2003, Gordon-Larsen2005, Leitzmann2007, Mendoza2011, Millett2013, Ming2008 |
| Medium | Quantitative modeling | 3 | Kahlmeier2010, MacMillan2014, Maizlish2013 |
| Medium | Literature review | 11 | de Rezende2014, Demark-Wahnefried2014, Gerber2009, Haskell2009, Litman2013, Lovasi2009, Lubans2011, McMillan2009, Nelson2007, Powell2011, Wareham2005 |
| Low | Case studies or small sample size | | |
| Low | Expert opinion, best practice, gray literature | | |

| Physical activity – mental health | Bicycling |
|---|---|
| **There is very strong evidence that physical activity is beneficial to mental health.** | |
| **Description of evidence base** | We reviewed 23 studies linking physical activity and mental health, all with consistent findings. Evidence supports an association between physical activity and mental health across the life course (childhood to old age). The CDC notes that regular physical activity can help maintain thinking, learning and judgment into old age, and that it also reduces symptoms of depression. The literature supports physical activity as both a preventive measure and an intervention for mental health. It also notes the mediating role physical activity and mental health play in recovery from diseases such as cardiovascular events or cancer. |
| **Remaining uncertainties** | The nature of the relationship between physical activity, active transportation and mental health is less certain. Much of the literature on physical activity and mental health focuses on leisure time physical activity or co-mingles leisure and non-leisure physical activity. Some investigators have noted that the mental health benefits of active transportation may vary by socioeconomic status, or might be less if active transportation is imposed rather than chosen. It is, therefore, difficult to state with confidence that active transportation universally leads to mental health benefits despite the clear association between physical activity and mental health. |
| **Assessment of confidence** | Very strong |

| Evidence reviewed: physical activity – morbidity and mortality | | | Bicycling |
|---|---|---|---|
| **Quality** | **Description** | **Count** | **Reference list** |
| High | Longitudinal/controlled experimental study | | |
| High | Systematic review/meta-analysis | 8 | Ahn2011, Biddle2011, Brown2013, Daley2008, Krogh2011, Mammen2013, Reiner2013, Tremblay2011 |
| Medium | Observational/cross-sectional | 4 | Asztalos2009, Humphreys2013, Olsson2013, Scarapicchia2014, Wener2011 |

| Evidence reviewed: physical activity – morbidity and mortality *(cont.)* | | | Bicycling |
|---|---|---|---|
| **Quality** | **Description** | **Count** | **Reference list** |
| Medium | Literature review | 7 | Coon2014, Hammer2012, Johnson2011, Mason2012, Teychenne2008, Teychenne2010, Tomporowski2011 |
| Medium | Quantitative modeling | | |
| Low | Case studies or small sample size | 4 | Fox2007, Gatersleben2007, LaJeunesse2012, Rubens2013 |
| Low | Expert opinion, best practice, gray literature | | |

| Traffic injuries | Bicycling |
|---|---|
| **There is moderate evidence that, compared to other travel modes, the risk of injury from bicycling is high.** | |
| **Description of evidence base** | There are reliable estimates of injury rates among people traveling by bicycle, but studies with comparable exposure-based injury rates across modes are few. We found only one study that provides injury and fatality rates based on exposure in person-trips and another based upon exposure based on miles traveled. Considering this mix of findings, we conclude that there is a moderate strength of evidence supporting the association between bicycling and elevated traffic injury rates. |
| **Remaining uncertainties** | There are clearly mitigating factors that reduce injuries — such as the presence of separated facilities, vehicle speed and other contextual factors — that make drawing conclusions difficult. Further complicating conclusions is the so-called "safety in numbers" effect observed in many cities. Whereas there is a clear correlation between greater numbers of cyclists and lower injury rates, the causal mechanism that could explain this correlation is poorly understood. |
| **Assessment of confidence** | Moderate |

| Evidence reviewed: traffic injuries | | | Bicycling |
|---|---|---|---|
| **Quality** | **Description** | **Count** | **Reference list** |
| High | Longitudinal/controlled experimental study | 4 | Aertsens2010, Beck2007, Pucher2011b, Roberts2013 |
| High | Systematic review/meta-analysis | 1 | Wong2011 |
| Medium | Observational/cross-sectional | 14 | Blaizot2013, Edwards2014, Harris2013, Hoffman2010, Jacobsen2003, Lovasi2013, Lusk2011, Mader2014, Minikel2012, Nordback2014, Schepers2012, Teschke2012, Winters2012, Yiannakoulias2012 |
| Medium | Quantitative modeling | 11 | deHartog2010, Graeme2011, MacMillan2014, Maizlish2013, Woodcock2014, Rabl2012, Rojas-Rueda2011, Sallis2013, Wei2012, Woodcock2009, Woodcock2014 |
| Medium | Literature review | 4 | deNazelle2011, Jacobsen2009, Lovasi2009, Reynolds2009 |
| Low | Case studies or small sample size | | |
| Low | Expert opinion, best practice, gray literature | 2 | Bhatia2011, Harris2011 |

| Exposure to pollutants | Bicycling |
|---|---|
| **There is moderate evidence that people traveling by bicycle are disproportionately exposed to harmful air pollutants.** | |
| **Description of evidence base** | Findings varied among the 25 studies that specifically addressed bicyclists' exposure to ambient air pollutants. The mix of findings on bicyclist exposure to air pollution prevents us from concluding that the strength of evidence is more than moderate. Whereas several studies show that bicyclists are exposed to high levels of vehicle emissions, there are many studies that show that vehicle passengers are also exposed to high levels of emissions. Contextual factors make it difficult to form broad conclusions comparing one mode of travel to another. |

| Exposure to pollutants *(continued)* | Bicycling |
|---|---|
| **Remaining uncertainties** | There is significant uncertainty as to how cyclist exposure compares to other modes. Contextual factors of the microenvironment such as weather, wind, traffic flow, time of day and route choice all appear to influence exposure; this is further complicated by personal dosage as a function of uptake and duration. Cyclists have the greatest uptake of any mode because of exertion, but may have a different length of exposure compared to other modes.<br><br>While many of the observational studies have small sample sizes, most have high-quality experimental designs suggesting the body of evidence will stabilize in the next five years. |
| **Assessment of confidence** | Moderate |

| Evidence reviewed: exposure to pollutants | | | Bicycling |
|---|---|---|---|
| **Quality** | **Description** | **Count** | **Reference list** |
| High | Longitudinal/controlled experimental study | | |
| High | Systematic review | 1 | Knibbs2011 |
| Medium | Observational/cross-sectional | 11 | Dons2012, Dons2013, Cole-Hunter2012, Hatzopoulou2013, Int Panis 2010, Kingham2013, Nyhan2013, MacNaughton2014, Weichenthal2011, Zuurbier2010, Zuurbier2011 |
| Medium | Quantitative modeling | 10 | Berghmans2009, Boogaard2009, de Nazelle2009, Gordon2012, Graeme2011, Holm2012, MacMillan2014, Maizlish2013, Rabl2012, Strauss2012 |
| Medium | Literature review | 1 | Bigazzi2014 |
| Low | Case studies or small sample size | 1 | Kendrick2011 |
| Low | Expert opinion, best practice, gray literature | 1 | Int Panis 2011 |

| Exposure to pollutants — morbidity and mortality | Bicycling |
|---|---|
| **There is very strong evidence that pollution from transportation sources is harmful to health.** | |
| **Description of evidence base** | We reviewed 49 studies suggesting that transportation emissions harm health. These studies show consistent results and large effect sizes, and many have high-quality longitudinal or experimental designs. Major scientific agencies — including the CDC, EPA, WHO and American Heart Association — consider there to be a causal relationship between auto emissions and health. |
| **Remaining uncertainties** | We know that, broadly speaking, vehicle pollutants are harmful to health and that distance to high-traffic areas is a significant health risk. We have less information about acute exposures by different travel modes due to uncertainty about microenvironments. There also remains uncertainty about mechanisms by which air pollution harms health, including which pollutant(s) result in specific health outcomes. |
| **Assessment of confidence** | Very strong |

| Evidence reviewed: exposure to pollutants — morbidity and mortality | | | Bicycling |
|---|---|---|---|
| **Quality** | **Description** | **Count** | **Reference list** |
| High | Longitudinal/controlled experimental study | 18 | Baleen2014a, Baleen2014b, Brunekreef2009, Chen2013, Dimakopoulou2014, Caiazzo2013, Gan2012, Gauderman2004, Hart2013, Hennig2014, Hoffmann2005, Hoffmann2007, Hoffmann2009a, Kälsch2014, Lepeule2012, Pope2009, Sørensen2012, Vineis2007 |
| High | Systematic review/meta-analysis | 6 | Brook2010, Chen2008, Janssen2011, Meng2013, WHO2003, WHO2013 |
| Medium | Observational/cross-sectional | 15 | Fuks2011, Hoffman2006, Hoffmann2009b, Kim2008, Lui2014, McConnell2006, McCreanor2007, Morabia2009, Nwokoro2012, Peters2013, Spira-Cohen2011, Strak2010, vanKempen2012b, Weichenthal2011, Zuurbier2010 |

| Evidence reviewed: exposure to pollutants — morbidity and mortality *(cont.)* | | | Bicycling |
|---|---|---|---|
| **Quality** | **Description** | **Count** | **Reference list** |
| Medium | Quantitative modeling | 4 | MacMillan2014, Maizlish2013, Xia2013, Zhang2013 |
| Medium | Literature review | 5 | Brugge2007, Gold2013, Hofmann2011, Kelishadi2011, Laumbach2010 |
| Low | Case studies or small sample size | | Kendrick2011 |
| Low | Expert opinion, best practice, gray literature | 1 | Forastiere2013 |

| Noise | Bicycling |
|---|---|
| **There is weak evidence that traffic noise disproportionately affects people traveling by bicycle.** | |
| **Description of evidence base** | Traffic noise is associated with negative health outcomes (see below). Expert opinion and theory posit a relationship, but there is minimal evidence. |
| **Remaining uncertainties** | There is very little research specifically linking bicycling with exposure to noise. Traffic noise studies typically focus on long-term (eight hours or more) exposure to traffic noise, rather than the episodic exposure that could be expected with active transportation. |
| **Assessment of confidence** | Weak |

| Evidence reviewed: exposure to pollutants | | | Bicycling |
|---|---|---|---|
| **Quality** | **Description** | **Count** | **Reference list** |
| High | Longitudinal/controlled experimental study | | |
| High | Systematic review | | |
| Medium | Observational/cross-sectional | 1 | Boogaard2009 |
| Medium | Quantitative modeling | | |
| Low | Case studies or small sample size | | |
| Low | Expert opinion, best practice, gray literature | | |

| Noise – morbidity and mortality | Bicycling |
|---|---|
| **There is very strong evidence that traffic noise is harmful to health.** | |
| **Description of evidence base** | We reviewed 43 studies linking morbidity and mortality to traffic noise exposure. These studies had consistent results and moderate effect sizes that seem to hold even when controlling for air pollution exposure. One of the strongest associations was between noise and myocardial infarction and/or hypertension with additional evidence of risk of diabetes and negative cognitive consequences for children. The literature draws heavily from residential exposure, implying long-term exposure particularly at night. |
| **Remaining uncertainties** | Most noise studies are not specific to active transportation and many are from long-term rather than short-term exposure, making it difficult to generalize.<br><br>Noise and air pollution are highly correlated. While Gan2012, Kalsch2014, Sørensen2012 and other studies suggest independent effects, future research is needed to understand the confounding relationship.<br><br>One branch of the traffic noise literature clearly describes annoyance as a result of exposure to traffic exposure. Annoyance seems to heighten negative health effects, likely through stress response, but the link between annoyance and other health outcomes could be more solid.<br><br>Threshold and dose-response are starting to be reported, but additional research is needed to fine-tune each. |
| **Assessment of confidence** | Strong |

| Evidence reviewed: noise – morbidity and mortality | | | Bicycling |
|---|---|---|---|
| **Quality** | **Description** | **Count** | **Reference list** |
| High | Longitudinal/controlled experimental study | 8 | Kälsch2014, Gan2012, Hart2013, Notbohm2013, Sørensen2011, Sørensen2012, Sørensen2013, Sørensen2014 |
| High | Systematic review/meta-analysis | 7 | Babisch2008, Babisch2014, Ndrepepa2011, Tetreault2013, Tomei2010, vanKempen2012a, WHO2011 |

| Evidence reviewed: noise – morbidity and mortality *(continued)* | | | Bicycling |
|---|---|---|---|
| **Quality** | **Description** | **Count** | **Reference list** |
| Medium | Observational/cross-sectional | 13 | Babisch2013, Banerjee2013, Birk2011, Chang2014, de Kluizenaar2013, Floud2013, Foraster2011, Fuks2011, Haralabidis2011, Liu2013, Liu2014, Huang2013, Kraus2013 |
| Medium | Literature review | 11 | Basner2014, Davies2012, Goins2007, Hammer2014, Kelishadi2011, Muenzel2014, Muzet2007, Pirrera2010, Seidman2010, vanCamp2013, vanKempen2012b |
| Medium | Quantitative modeling | 1 | Harding2013 |
| Low | Case studies or small sample size | | |
| Low | Expert opinion, best practice, gray literature | 3 | Kairns2014, Foraster2013, Holzman2014 |

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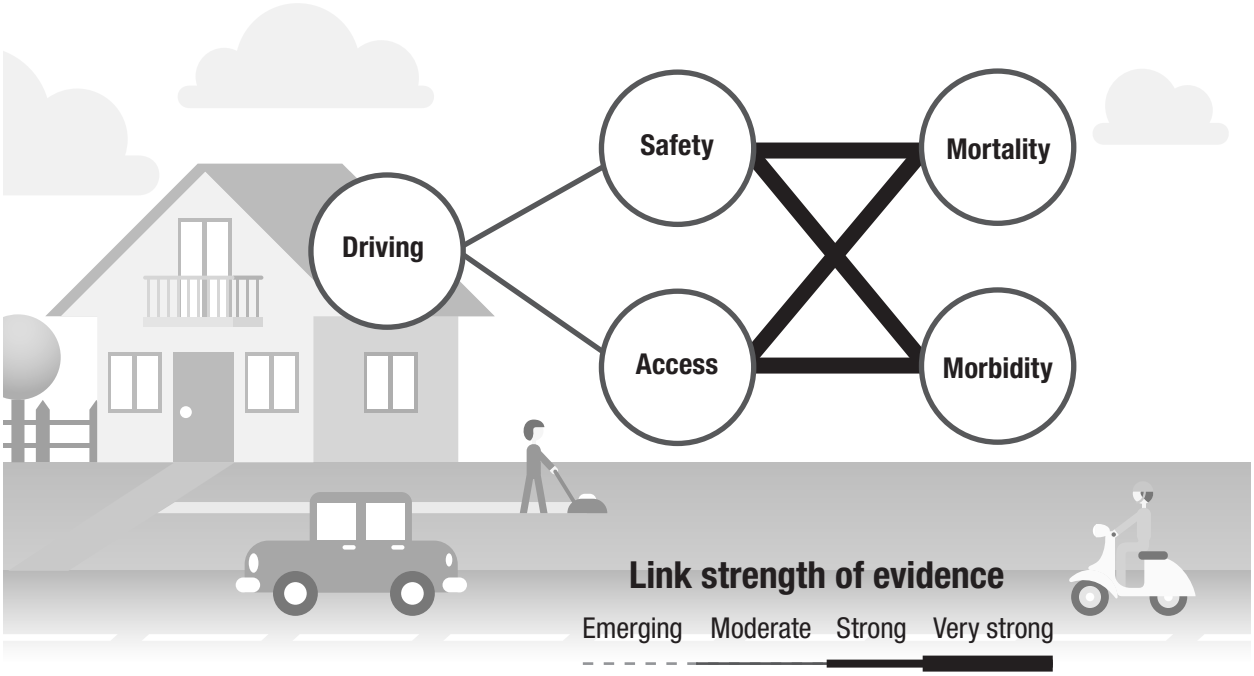
# Driving and health

Part of a series of research briefs on the health impacts of transportation options in Oregon

## Health benefits

There is limited evidence on health benefits of driving. The causal pathways are approximated in Figure 1.

Figure 1. **Pathway of health benefits from driving**




## Access

**There is moderate evidence that, in the absence of other travel options, driving provides access to resources that support health**. Cars can provide access to destinations critical to self-care such as employment, food retail and health care. For example, there is some evidence that welfare recipients are more likely to gain employment (and the health advantages the come with it) when they have access to a private automobile.[1,2] Several studies have examined the role of automobiles in accessing food.[3] While findings are somewhat mixed, it appears that households without access to cars are more limited in their food choices within their immediate environment than those with cars.[4] Like employment and food retail, access to cars mediates health care.[5] One study found that travel by car was associated with a greater likelihood of keeping medical appointments.[6] Approximately 8 percent of Oregon households have no vehicle available.[7]

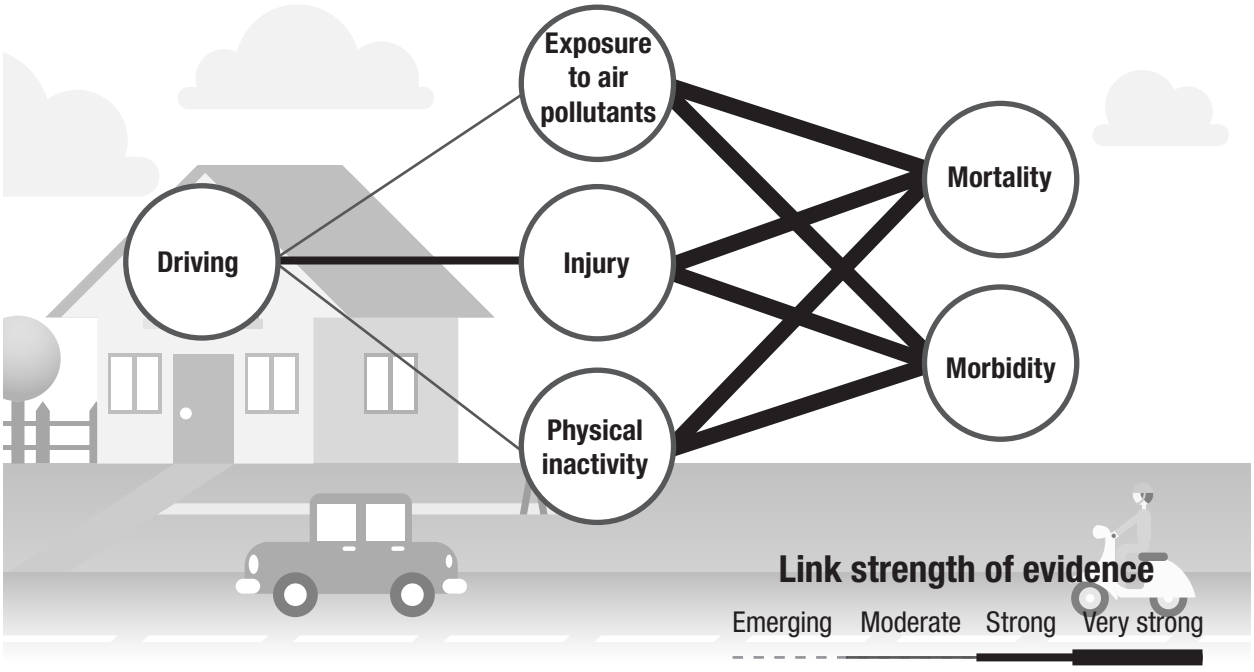
## Safety

There is moderate evidence that traveling by passenger vehicle is safer than some other modes. Traveling by passenger vehicle is safer than traveling by motorcycle, walking or bicycling on a per-trip basis.[8] There are differences by gender. The most cited study (Beck et al. 2007) on this topic found no statistically significant difference in risk between driving and bicycling for females, who have a lower risk of injury across all modes. However, this benefit should not be overstated. Unintentional injuries, including those resulting from traffic crashes, are a leading cause of premature death in Oregon, and the leading cause of injury death for Oregonians aged 4 to 25.[9]

## Risks

Figure 2 depicts causal pathways from driving to health outcomes. Risks of driving include leading causes of death such as injuries from traffic crashes, exposure to pollution and physical inactivity.

Figure 2. **Pathway of health risks from driving**



## Injuries

**There is very strong evidence of injury risks from traveling by car**. Although statistically safer than some modes, fatality rates were 23 times higher for passenger vehicles than for transit.[10] Motor vehicle crashes are the leading cause of death in the United States among those aged 5–34.[11] In Oregon, unintentional injury is a leading cause of death for ages 1–64, and traffic crashes are a major contributor.[12,13] In 2012, there were 266 deaths and approximately 34,000 injuries among vehicle occupants in Oregon.[14] Of the 366 traffic deaths in Oregon in 2012, 103 (31 percent) were related to alcohol.[15]

## Air pollution

**There is very strong evidence of individual and population-level risk from vehicle emissions**. Traffic-related pollutants are associated with many negative health effects, including respiratory illness, cardiovascular disease, lung cancer, adverse pregnancy outcomes and cardiopulmonary mortality.[16] The magnitude of these effects is very large at the population level; a 2013 study estimated that air pollution from vehicles causes more deaths than traffic crashes.[17] One measure of vulnerability to air pollution is the proportion of the population with existing respiratory illness. An estimated 11 percent of Oregon adults have asthma, the sixth highest percentage of adults with asthma among U.S. states.[18]

**There is moderate evidence of disparities in exposure to air pollution from transportation sources**. Commuting is a high-exposure activity, but the evidence is unclear about disparities in both exposure and dose by commute mode.[19,20] Dose is a function of microenvironment concentration, exposure time and respiratory rate. Evidence is mixed as to whether or not in-vehicle concentrations are higher in cars than for other modes.[21,22,23] Emerging evidence suggests factors such as age of vehicle, position of windows and air circulation explain wide variation of concentrations within the vehicle.[24] Disparities in exposure have been observed by location as well as by mode. For example, place of residence is a known risk factor for air pollution exposure; households living closest to a highway are at greatest risk.[25,26] There is evidence that drivers do not spend more time commuting than people commuting by walking or biking and their respiratory rates should be lower than other more active transportation modes, suggesting overall dosage is lower for driving than other travel modes. In Oregon, the median commute time by car is similar to that of most active modes, but somewhat lower than transit commute times.[27]

## Physical inactivity

**There is strong evidence that driving contributes to physical inactivity**. Many studies have associated time spent driving with physical inactivity or obesity. Ecological and cross-sectional studies consistently show associations between auto-dependency

and higher body mass index.[28,29,30,31,32,33] One study estimated that every additional hour spent per day driving increases the odds of obesity by 6 percent.[34] Another recent study found that commuting by active modes is associated with significantly lower body mass index.[35] Leading researchers describe changes in travel behavior as a major contributor to declining rates of physical activity in the United States.[36,37]

**There is very strong evidence that physical inactivity contributes to morbidity and mortality**. When combined with unhealthy diets, physical inactivity is the second leading cause of death, rivaling tobacco as a cause of death in the United States.[38] Physical activity is beneficial to health regardless of weight or diet. This is due to associations between physical activity and many common diseases, including diabetes, cardiovascular disease, breast cancer, colon cancer and dementia.[39] Compared to being inactive, having a physical activity level at or above the recommended 150 minutes of moderate activity per week is associated with an increased life expectancy of between 3.4 and 4.5 years.[40] Lack of regular exercise and obesity could result in the current generation of youth living shorter, less healthy lives than their parents.[41]

# Conclusions

**Driving is the least healthy travel option where active options exist**. Whereas there is clear evidence that active transportation benefits health largely through physical activity, there is little evidence documenting benefits from driving. For trips that active transportation could replace, such as those shorter than three miles, there is strong evidence that doing so would result in health benefits.

**Driving contributes to the leading causes of premature death**. Physical inactivity, air pollution and traffic crashes are major contributors to disease and death including chronic disease and unintentional injuries. Risks from physical inactivity affect drivers and passengers, but air pollution and traffic crashes are risks to the entire population, many of whom are unable to avoid exposure.

# Traceable accounts

Traceable accounts provide a summary of evidence reviewed for each of the associations and findings made above.

| Access | Driving |
|---|---|
| **There is moderate evidence that, in the absence of other travel options, driving provides access to resources that support health.** | |
| **Description of evidence base** | Studies show associations between automobile access and improved determinants of health, especially jobs. There is a substantial body of evidence that transportation in general is a barrier to health care. Literature describing access to food and food deserts is conflicted. Studies sometimes include analysis of automobile access, but conclusions about the role of cars are rare. Ver Ploeg et al. (2009) found that in high access areas, only 65 percent of low-income residents accessed supermarkets by car, suggesting that cars are not necessary for accessing food. At least one study (Fuller, 2013) found mode of transport to food stores has no significant impact on fruit and vegetable consumption. |
| **Remaining uncertainties** | There is uncertainty about the role of cars in accessing food. Inagami (2009) found that the density of restaurants was a stronger predictor of BMI than car ownership for local residents who do not have access to cars. Bodor et al. (2013) found associations between fruit and vegetable intake and local food retail environments among non-car owners, but not among car owners. Sharkey et al. (2010) found better access to healthy food in neighborhoods with low levels of car ownership. Caspi et al. (2012) found that perceived distance to supermarkets is strongly associated with fruit and vegetable consumption, but that actual distance is not. These findings suggest that cars modify the impact of the local food environment on diet, but do not provide insight as to whether cars facilitate healthy diets.<br><br>There are few studies comparing cars to other modes. It appears that automobile access provides an advantage over poor transit service, but this relationship is unclear. It may be that cars always offer an advantage, or that this advantage erodes as transit service improves. |
| **Assessment of confidence** | Moderate |

| Evidence reviewed: access | | | Driving |
|---|---|---|---|
| **Quality** | **Description** | **Count** | **Reference list** |
| High | Longitudinal/controlled experimental study | | |
| High | Systematic review/meta-analysis | | |
| Medium | Observational/cross-sectional | 7 | Blumenberg2014, Baum2009, Bodor2013, Inagami2009, Sharkey2010, Yang2006, Ver Ploeg2009 |
| Medium | Quantitative modeling | | |
| Medium | Literature review | 1 | Syed2013 |
| Low | Case studies or small sample size | | |
| Low | Expert opinion, best practice, gray literature | | |

| Safety/injury (combined benefit and risk) | Driving |
|---|---|
| **There is moderate evidence that driving is safer than some other modes. There is very strong evidence of safety risks from traveling by car.** | |
| **Description of evidence base** | In absolute terms, motor vehicle crashes are a prominent danger to health, but rates show that driving is safer than some modes. There is strong evidence that motor vehicle crashes are a primary contributor to a leading cause of death for ages 44 and under. Comprehensive data from transportation and public health agencies support this. We found only one high-quality domestic study that estimated risk normalized for exposure (fatalities per person trip). This study by Beck et al. (2007) is widely cited and is based on sound data, elevating the credibility of its conclusions. The authors found a higher risk among pedestrians, bicyclists and motorcyclists than for those traveling by passenger car. Notably, transit is many times safer than driving.<br><br>Studies from abroad were given less weight because of large differences between traffic injury rates among countries.<br><br>The single study, albeit strong, leads us to characterize the evidence as moderate. The combination of our finding that motor vehicles crashes are a leading cause of death for some age groups and that transit is vastly safer than automobile travel suggest that messages about the safety of driving should be moderated. |

| Safety/injury (combined benefit and risk) *(continued)* | Driving |
|---|---|
| **Remaining uncertainties** | Studies with comparable exposure-based injury rates across modes are rare. Additional analysis of risk normalized by exposure could confirm or correct the conclusions of the 2007 study by Beck et al. This could substantially change our conclusions.<br><br>Unresolved issues of measurement in this field of research could influence our conclusions. Some studies (Haddak 2014, Teschke 2013) found different risks by mode depending on the measure of exposure used (hours traveled, kilometers travelled, etc.). If person-trips are used as a metric of exposure, then the definition of a trip becomes very important, especially when trips are multi-modal (see Marmor, 2007). A major limitation of Beck et al. (2007) is that the definition of a trip attributes pedestrian travel on either end of a trip by another mode to the pedestrian mode. For example, if a transit passenger is killed while accessing a transit stop, the fatality is attributed to the pedestrian mode.<br><br>Segui-Gomez et al. (2011) point out that most studies measure the population burden of traffic crashes rather than individual risk. Fuller (2013) notes that the causes of population incidence are different from the causes of individual cases. |
| **Assessment of confidence** | Moderate safety benefit; very strong injury risk. |

| Evidence reviewed: Safety/injury | | | Driving |
|---|---|---|---|
| **Quality** | **Description** | **Count** | **Reference list** |
| High | Longitudinal/controlled experimental study | 2 | Beck2007, Segui-Gomez2011 |
| High | Systematic review/meta-analysis | | |
| Medium | Observational/cross-sectional | 6 | Blaizot2013, Haddak2014, MacAndrews2011, Mindell2012, Teschke2013 |
| Medium | Quantitative modeling | 1 | Woodcock2009 |
| Medium | Literature review | 1 | Litman2013 |
| Low | Case studies or small sample size | | |
| Low | Expert opinion, best practice, gray literature | 2 | Marmor2007, Fuller2013 |

| Exposure to pollutants | Driving |
|---|---|
| **There is moderate evidence of disparities in exposure to air pollution from transportation sources.** | |
| **Description of evidence base** | Many variables influence both exposure and uptake for all modes. Further research on microclimates by mode could change our interpretation of the variation by mode or disproportionate exposure, but it is unlikely that we would change our conclusion that people traveling by car are exposed to harmful air pollutants. |
| **Remaining uncertainties** | Many studies have found exposure to pollutants occurring during car travel or in proximity to traffic. However, there were somewhat mixed results about any disproportionate exposure compared to other modes. |
| **Assessment of confidence** | Moderate |

| Evidence reviewed: exposure to pollutants | | | Driving |
|---|---|---|---|
| **Quality** | **Description** | **Count** | **Reference list** |
| High | Longitudinal/controlled experimental study | 2 | Caiazzo2013, Bigazzi2012 |
| High | Systematic review/meta-analysis | 2 | Knibbs2011, Woodcock2009 |
| Medium | Observational/cross-sectional | 2 | Dons2012, Knibbs2010 |
| Medium | Quantitative modeling | 1 | De Nazelle2009 |
| Medium | Literature review | 1 | Brugge2007, Ragland2011 |
| Low | Case studies or small sample size | | |
| Low | Expert opinion, best practice, gray literature | | |

| Physical inactivity | Driving |
|---|---|
| **There is strong evidence that driving contributes to physical inactivity.** | |
| **Description of evidence base** | We reviewed 19 high-quality studies linking driving, car ownership, physical activity levels and/or body mass index. Studies consistently show associations between driving and physical inactivity and/or BMI. Further research is likely to enhance our understanding of this relationship, but unlikely to alter our conclusion. |
| **Remaining uncertainties** | Studies that directly link BMI and travel mode often rely on self-reported height and weight. While this approach is generally accepted for surveillance purposes, objective measures are preferable for characterizing causal relationships.<br>The majority of the literature directly linking physical inactivity and travel mode choice are cross-sectional. More longitudinal studies would strengthen our confidence in this relationship. |
| **Assessment of confidence** | Strong |

| Evidence reviewed: driving – physical inactivity | | | Driving |
|---|---|---|---|
| **Quality** | **Description** | **Count** | **Reference list** |
| High | Longitudinal/controlled experimental study | 3 | Morabia2010, Morabia2012, Sugiyama2013 |
| High | Systematic review/meta-analysis | 1 | Woodcock2009 |
| Medium | Observational/cross-sectional | 13 | Audrey2014, Basset2008, Flint2014, Frank2006, Frank2005, Frank2004, Gordon-Larsen2005, Hoehner2012, Inagami2009, Marshall2014, Pendola2007, Pucher2010, Swanson2012 |
| Medium | Quantitative modeling | 2 | Maizlish2013, Woodcock2009 |
| Medium | Literature review | | |
| Low | Case studies or small sample size | | |
| Low | Expert opinion, best practice, gray literature | | |

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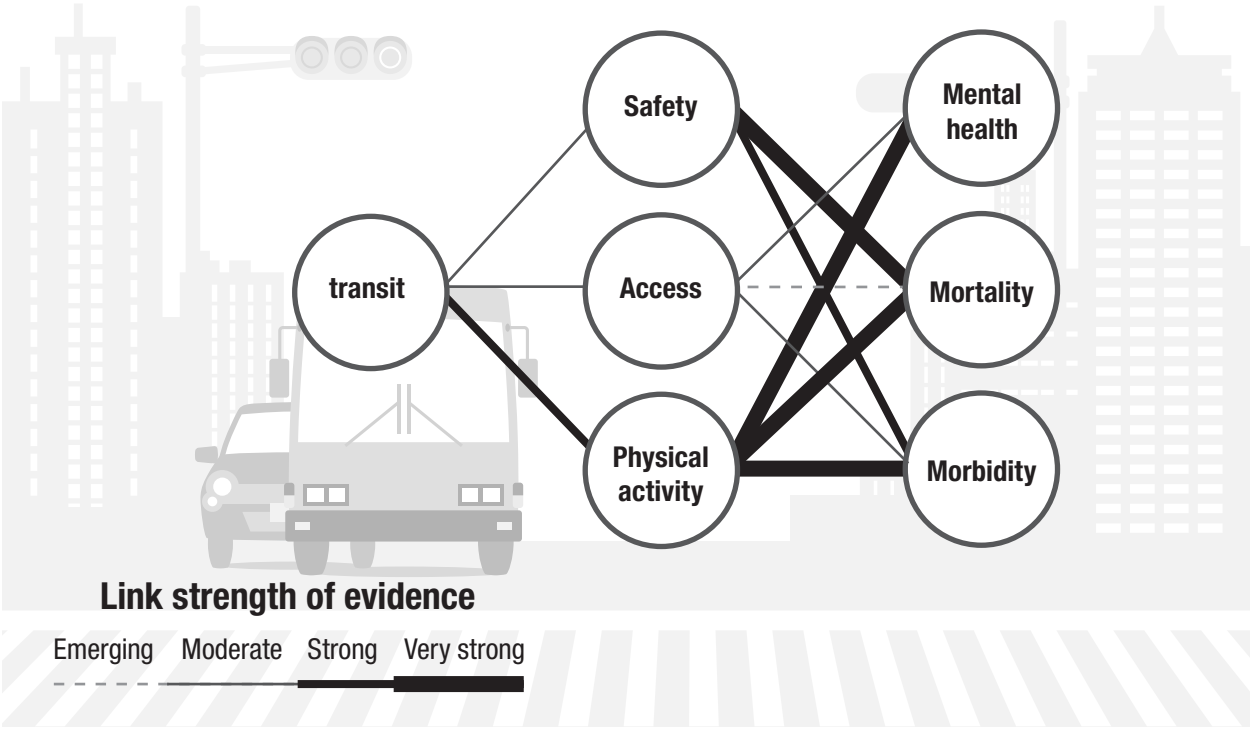
# Transit and health

Part of a series of research briefs on the health impacts of transportation options in Oregon

## Health benefits

The health benefits of riding transit are displayed in Figure 1 below. These include benefits from physical activity, access to health-supportive resources, and safety from traffic crashes.

Figure 1. **Pathway of benefits from transit**




## Physical activity

**There is very strong evidence that physical activity is beneficial to health**. Benefits of physical activity include reduced risk of cardiovascular disease, type 2 diabetes and some cancers, especially colon and breast cancer. Additionally, physical activity reduces the risk of obesity, strengthens bones and muscles, prevents falls, and extends life expectancy. Physical activity is beneficial to health regardless of weight or diet, even in small doses.[1]

The Centers for Disease Control and Prevention (CDC) recommends 150 minutes per week of moderate intensity physical activity for adults (or 75 minutes of vigorous physical activity), along with two days per week of muscle-strengthening activity such as weightlifting or yoga.[2] Compared to being inactive, having a physical activity level at or

above the recommended 150 minutes of moderate activity is associated with an increased life expectancy of between 3.4 and 4.5 years.[3] Adherence to this recommendation is associated with a 20–30 percent reduction in the risk of death from all causes.[4] Additional physical activity beyond these recommendations results in additional health benefits, but there is evidence that the majority of health benefits occur in the first 30 minutes of activity.[5] In 2013, approximately 25 percent of Oregon adults participated in enough aerobic and muscle-strengthening exercises to meet physical activity guidelines, and approximately 19 percent reported no physical activity.[6]

**There is strong evidence that accessing transit by active transportation is beneficial to physical health**. Walking for both recreational and utilitarian purposes is associated with an increased likelihood of meeting physical activity recommendations.[7] Accessing transit by walking or cycling provides an opportunity for physical activity,[8] and nearly one-third of transit users meet physical activity recommendations by walking to and from transit.[9,10] One study found that using a newly opened light rail line was associated with a relative weight loss of more than six pounds for a medium-height person.[11] Experts view walking for transportation as an intervention with high potential due to its accessibility and low cost.[12] According to 2008–2012 census estimates, approximately 4 percent of Oregonians walk to work.[13] National data (2009) suggest that approximately 10 percent of all trips are made on foot, and walking constitutes an estimated 57 percent of all physical activity among adults.[14,15]

## Safety

**There is moderate evidence that traveling by transit is safer than other modes**. Available evidence suggests that transit is among the safest modes of travel. One study found that the fatality rate per 100 million person-trips was just 0.4 for bus riders, compared to 9.2 for car travel, 13.7 for walking and 21.0 for cycling.[16] Per mile traveled, the fatality rate among passenger car travelers is estimated to be 28 times greater than for bus passengers, and 71 times greater than for rail transit passengers.[17] In 2010, there were more than 32,000 highway deaths in the United States, but only 215 transit deaths.[18]

## Mental health

**There is strong evidence that physical activity is beneficial to mental health**. Extensive research suggests that physical activity can reduce symptoms of depression and improve mood and self-reported well-being.[19] Studies have found physical activity to be effective treatment for depression.[20] Although two-thirds of Oregonians report good mental health (2006–2009),[21] in 2010, Oregon's suicide rate was in the top 10 among U.S. states.[22]

**There is minimal evidence on transit and mental health**. Little attention has been devoted to direct links between walking to transit and mental health, so it is difficult to characterize whether there is any relationship. However, transit is thought to benefit mental

health in ways other than through physical activity. There is some evidence that commuting by transit is less stressful than commuting by car, attributed to the effort and perceived unpredictability of car travel.[23] Other studies have found that transit provides stress relief indirectly through access to jobs and other resources.[24]

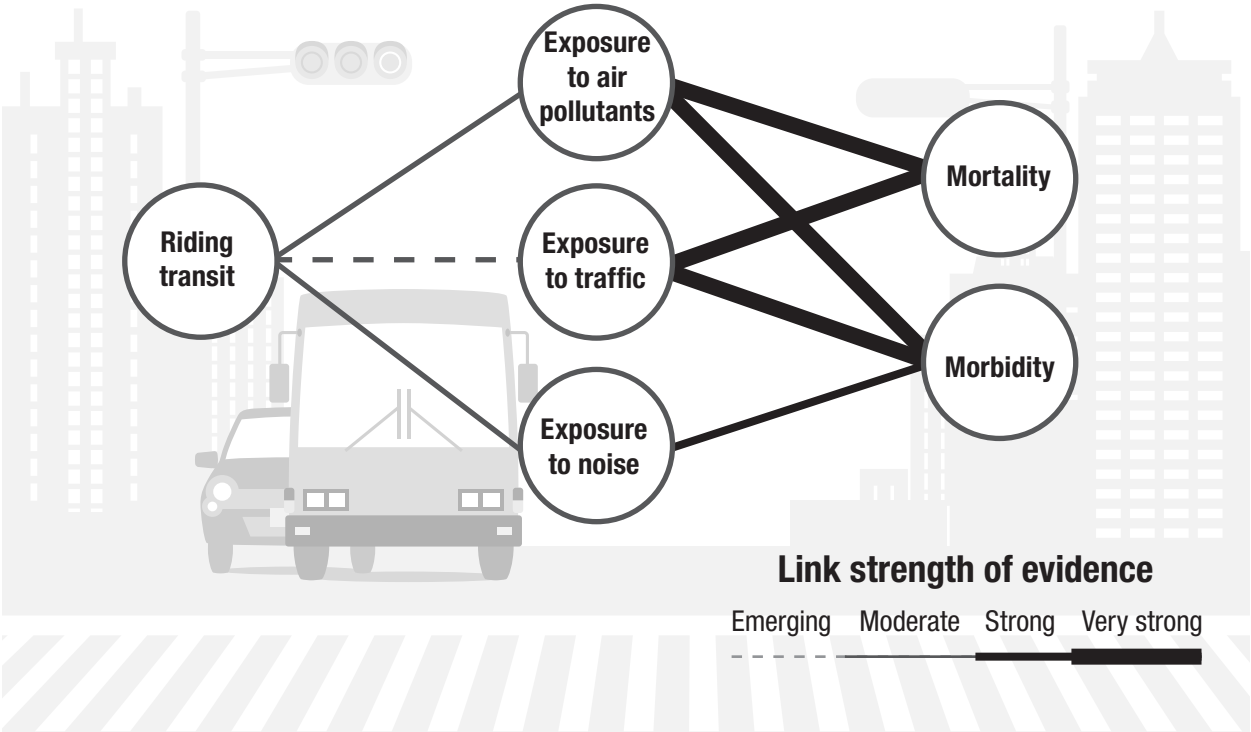
## Safety

**There is moderate evidence that transit enables access to resources that support health**. Transit access is seen as providing basic mobility for those with few other options and has long been a platform for advancing civil rights.[25,26] Among some populations, access to available transit provides a critical link to health care.[27]

## Risks

Risks from riding transit are outlined in the pathway diagram below (Figure 2). Riding transit can lead to exposure to risks from pollutants and noise.

Figure 2. **Pathway of risks from transit**




## Air pollution

There is very strong evidence that pollution from traffic is harmful to health. Many observational and experimental studies have shown negative impacts from vehicle emissions, including respiratory illness, cardiovascular disease and cancer.[28,29,30] One recent study estimated that air pollution from transportation rivals traffic crashes as a

cause of death.[31] In 2011, Oregon had the sixth highest percentage of adults with asthma among U.S. states, and asthma hospitalizations in the state cost more than $28 million.[32]

**Mixed evidence exists regarding the association between transit and exposure to harmful air pollutants**. All roadway users are exposed to harmful air pollutants. The amount of pollutant exposure experienced by people on transit can be higher or lower compared to other modes; this appears to depend on the type of vehicle in use. For example, exposure on diesel buses is higher than other modes, but exposure on electric buses is lower than other modes.[33] A review of 47 studies found that ultra-fine particle exposure is slightly lower in buses than in cars, and slightly lower in cars than on rail.[34] The same study suggested that the broad range of influences on exposure, such as meteorology, traffic patterns, fuel type, ventilation, roadside air pollution concentrations and other factors make ranked comparisons between modes uncertain.

### Injuries

**There is minimal evidence that accessing transit increases risk of injury**. Accessing transit is accomplished by one or more other travel modes, each of which carries a degree of risk. There are few studies that compare risks across modes, but available data suggest that risk is higher for bicycling than walking, and higher for walking than traveling by car.[35] One study found that bus stop usage on large urban state highways is associated with pedestrian collisions.[36]

### Noise

**There is moderate evidence that noise from transit is harmful**. Noise from traffic is generally harmful, but some studies show that noise from transit can damage hearing for both users and non-users. One study found that approximately one in 10 transit users were exposed to harmful levels of noise from transit.[37] Another found that both bus and rail transit produce noise above thresholds at which hearing loss is considered possible.[38]

## Conclusions

**Shifting from car travel to transit is likely to be beneficial for health**. Compared to traveling by car, transit is safer and incorporates more physical activity. The physical activity necessary to access transit is associated with lower body mass index and can help prevent chronic diseases like heart disease, diabetes and cancer.

**Riding transit can protect riders from leading causes of death**. Diseases related to physical inactivity are among the leading causes of death in the United States and in Oregon, and traffic crashes are a leading cause of death for youth and young adults. Riding transit protects from both of these because of the low fatality rates and physical activity achieved through accessing transit stops. These benefits are especially important for disadvantaged populations with a high burden of disease.

# Traceable accounts

Traceable accounts provide a summary of evidence reviewed for each of the associations and findings made above.

| Physical activity | Transit |
|---|---|
| **There is strong evidence that accessing transit by active transportation is beneficial to physical health.** | |
| **Description of evidence base** | A body of cross-sectional studies with very consistent results suggests that transit users achieve more physical activity than non-transit users. A 2012 systematic review (Rissel) estimated the additional activity achieved by transit users is in the range of 8–33 minutes/day. New transit service creates the opportunity for natural experiments, which researchers have recently been exploiting to understand the links between transit and physical activity. In addition to this set of cross-sectional research, a new group of longitudinal or pre/post studies have been published that take advantage of the natural experiment that occurs when new transit service is introduced. We reviewed just four of these studies, but we expect other sources to have the same findings.<br><br>A further improvement in this line of research is the use of GPS and accelerometers to objectively measure physical activity associated with transit. Since walking is thought to be under-reported, this advance improves our confidence in findings from such studies. |
| **Remaining uncertainties** | It is unclear what impact the use of park and rides has on the physical activity benefits of transit use.<br><br>While it appears that physical activity from accessing transit is not supplanting other physical activity, additional research is needed to confirm this.<br><br>Since some of the longitudinal studies are from settings in which transit use is already common (for example, the addition of a light rail line to a neighborhood with existing bus service), it is unclear how transferable some of the findings are to other neighborhoods.<br><br>Very little research has been conducted specifically on those accessing transit by bicycle. |
| **Assessment of confidence** | Strong |

| Evidence reviewed: physical activity | | | Transit |
|---|---|---|---|
| **Quality** | **Description** | **Count** | **Reference list** |
| High | Longitudinal/controlled experimental study | 4 | Brown2008, Brown2007, Macdonald2010, Saelens2014 |
| High | Systematic review/meta-analysis | 1 | Rissel2012 |
| Medium | Observational/cross-sectional | 10 | Besser2005, Edwards2008, Freeland2013, Gordon-Larsen2005, LaChapelle2012, LaChapelle2011, LaChapelle2009, Morabia2010, Wasfi2013, Wener2011 |
| Medium | Quantitative modeling | 2 | LaChapelle2011, Morency2011 |
| Medium | Literature review | 1 | Litman2013 |
| Low | Case studies or small sample size | 1 | Bopp2013 |
| Low | Expert opinion, best practice, gray literature | | |

| Physical activity – morbidity and mortality | | Transit |
|---|---|---|
| **There is very strong evidence that physical activity is beneficial to individual health.** | | |
| **Description of evidence base** | There is near scientific consensus that physical activity has a causal relationship with morbidity and mortality. The CDC cites a vast body of evidence showing that physical activity reduces risk of type 2 diabetes, cardiovascular disease and cancer, which are among the leading causes of death. Physical activity also appears to moderate stress, reducing stress-related illness. Physical activity also appears to have a prescriptive effect in lowering the risk of death for those already diagnosed with diabetes or heart disease.<br><br>We reviewed more than 58 studies that consistently demonstrate this relationship. Evidence linking physical activity with morbidity and mortality is high quality, often from longitudinal experiments. We are very confident in this conclusion. | |

| | |
|---|---|
| **Remaining uncertainties** | The nature of the dose-response relationship between physical activity and illness/death is not fully understood. Evidence clearly shows that some physical activity is better than no activity, and that there are additional benefits from additional activity. However, the rate at which benefits accrue, particularly by activity-type and intensity, is uncertain. |
| **Assessment of confidence** | Very strong |

| **Evidence reviewed: physical activity – morbidity and mortality** | | | **Transit** |
|---|---|---|---|
| **Quality** | **Description** | **Count** | **Reference list** |
| High | Longitudinal/controlled experimental study | 17 | Anderson2000, Arem2013, Barlow2013, Belavia2013, Ekelund2013, Hu2005, Lee2010, Luoto2000, Je2013, Moe2013, Menschik2008, Shmid2014, Shortreed2013, Wanner2014, Wen2014, Zhao2014, Zhou2014 |
| High | Systematic review/meta-analysis | 20 | Fogelholm2010, Goncalves2014, Guenther2011, Guh2009, Hamer2008, Kruk2007, Lee2001, Johnson2013, Loprinzi2014, Moore2012, Nocan2008, Oja2011, Pucher2010, Rauner2013, Reiner2013, Saunders2013, Schmitz2005, Stephens2014, Wanner2012, Woodcock2011 |
| Medium | Observational/cross-sectional | 7 | Brown2013, Hu2003, Gordon-Larsen2005, Leitzmann2007, Mendoza2011, Millett2013, Ming2008 |
| Medium | Quantitative modeling | 3 | Kahlmeier2010, MacMillan2014, Maizlish2013 |
| Medium | Literature review | 11 | de Rezende2014, Demark-Wahnefried2014, Gerber2009, Haskell2009, Litman2013, Lovasi2009, Lubans2011, McMillan2009, Nelson2007, Powell2011, Wareham2005 |

| Evidence reviewed: physical activity – morbidity and mortality *(cont.)* | | | Transit |
|---|---|---|---|
| **Quality** | **Description** | **Count** | **Reference list** |
| Low | Case studies or small sample size | | |
| Low | Expert opinion, best practice, gray literature | | |

| Physical activity – mental health | | Transit |
|---|---|---|
| **There is very strong evidence that physical activity is beneficial to mental health.** | | |
| **Description of evidence base** | We reviewed 23 studies linking physical activity and mental health, all with consistent findings. Evidence supports an association between physical activity and mental health across the life course (childhood to old age). The CDC notes that regular physical activity can help maintain thinking, learning and judgment into old age, and that it also can reduce symptoms of depression. The literature supports physical activity as both a preventive measure and an intervention for mental health. It also notes the mediating role physical activity and mental health play in recovery from disease such as cardiovascular events or cancer. | |
| **Remaining uncertainties** | The nature of the relationship between physical activity, active transportation and mental health is less certain. Much of the literature on physical activity and mental health focuses on leisure time physical activity or co-mingles leisure and non-leisure physical activity. Some investigators have noted that the mental health benefits of active transportation may vary by socioeconomic status, or might be less if active transportation is imposed rather than chosen. It is, therefore, difficult to state with confidence that active transportation universally leads to mental health benefits despite the clear association between physical activity and mental health. | |
| **Assessment of confidence** | Very strong | |

| Evidence reviewed: physical activity – mental health | | | Transit |
|---|---|---|---|
| **Quality** | **Description** | **Count** | **Reference list** |
| High | Longitudinal/controlled experimental study | | |
| High | Systematic review/meta-analysis | 8 | Ahn2011, Biddle2011, Brown2013, Daley2008, Krogh2011, Mammen2013, Reiner2013, Tremblay2011 |

| Evidence reviewed: physical activity – mental health *(continued)* | | | Transit |
|---|---|---|---|
| **Quality** | **Description** | **Count** | **Reference list** |
| Medium | Observational/cross-sectional | 4 | Asztalos2009, Humphreys2013, Olsson2013, Scarapicchia2014, Wener2011 |
| Medium | Literature review | 7 | Coon2014, Hammer2012, Johnson2011, Mason2012, Teychenne2008, Teychenne2010, Tomporowski2011 |
| Medium | Quantitative modeling | | |
| Low | Case studies or small sample size | 4 | Fox2007, Gatersleben2007, LaJeunesse2012, Rubens2013 |
| Low | Expert opinion, best practice, gray literature | | |

| Access | Transit |
|---|---|
| **There is moderate evidence that transit enables access to resources that support health.** | |
| **Description of evidence base** | We reviewed seven studies on transit and access to health supportive resources, particularly health care. Among the most compelling was one that demonstrated a drop in pre-natal care visits among low-income mothers during a transit strike. There seems to be basic evidence that transit provides access to health care. |
| **Remaining uncertainties** | This becomes a difficult pathway to evaluate when one considers the inherent comparisons. There is an important distinction between a transit/no-transit comparison and a transit/cars comparison. In an example of the latter, a recent study found no difference in fruit and vegetable consumption based on the mode of accessing food retail. Importantly, there are consistent findings showing that access to transit is not a predictor of employment among welfare recipients; however, owning a car is an employment predictor. |
| **Assessment of confidence** | Moderate |

| Evidence reviewed: access | | | Transit |
|---|---|---|---|
| **Quality** | **Description** | **Count** | **Reference list** |
| High | Longitudinal/controlled experimental study | | Evans2005 |
| High | Systematic review/meta-analysis | | |
| Medium | Observational/cross-sectional | | Cervero2002, Fuller2013, Safrestano2014, Sanchez2004, Sanchez1999 |
| Medium | Literature review | | |
| Medium | Quantitative modeling | | |
| Low | Case studies or small sample size | | |
| Low | Expert opinion, best practice, gray literature | | Bullard2003 |

| Traffic injuries | Transit |
|---|---|
| **There is moderate evidence that, compared to other travel modes, the risk of injury from transit is low.** | |
| **Description of evidence base** | There are few studies on transit injury and fatality rates. In fact, research articles on ergonomic injuries to transit workers and suicides in metro stations are more readily available than research on crash-related injuries. Some researchers reported that numerator data were unavailable to calculate rates for transit fatalities, but the lack of studies may indicate that traffic injuries from transit don't rise to researchers' attention. Government reports are helpful in this regard, and the two reliable comparisons we found between transit and other modes provide compelling evidence that transit is far safer than other modes of transportation. We conclude that there is a moderate strength of evidence supporting the association between transit and elevated traffic injury rates. |
| **Remaining uncertainties** | Injuries and fatalities related to transit may be under-reported because of the pedestrian or bicycle trips required to access transit stops. Crashes that occur during these access trips may be attributed to the mode of access rather than to transit itself. Thus, there may be a greater risk of using transit than might be surmised from data attributed only to in-vehicle travel. |
| **Assessment of confidence** | Moderate |

| Evidence reviewed: traffic injuries | | | Transit |
|---|---|---|---|
| **Quality** | **Description** | **Count** | **Reference list** |
| High | Longitudinal/controlled experimental study | 2 | Beck2007, Chambers2012 |
| High | Systematic review/meta-analysis | | |
| Medium | Observational/cross-sectional | | |
| Medium | Quantitative modeling | | |
| Medium | Literature review | | |
| Low | Case studies or small sample size | | |
| Low | Expert opinion, best practice, gray literature | | |

| Exposure to pollutants | Transit |
|---|---|
| **There is moderate evidence that people traveling by transit are disproportionately exposed to harmful air pollutants.** | |
| **Description of evidence base** | We reviewed 15 studies on exposure to air pollution across modes. Because of the mixed findings, we conclude the strength of evidence is moderate. Contextual factors make it difficult to form broad conclusions comparing one mode of travel to another. These include the type of transit, type of vehicle, ventilation, frequency and length of travel, and others. Studies comparing across modes do not report differences of the same magnitude or direction, and findings vary depending on the pollutant being examined. The best conclusion may be that there is potential for exposure. Further research would almost certainly influence our conclusions about this relationship. |
| **Remaining uncertainties** | There is significant uncertainty as to how exposure varies by mode. Contextual factors of the microenvironment such as weather, wind, traffic flow, time of day and route choice all appear to influence exposure; this is further complicated by dosage as a function of uptake and duration. |
| **Assessment of confidence** | Moderate |

| Evidence reviewed: exposure to pollutants | | | Transit |
|---|---|---|---|
| **Quality** | **Description** | **Count** | **Reference list** |
| High | Longitudinal/controlled experimental study | 1 | Kaur2009 |
| High | Systematic review/meta-analysis | 1 | Knibbs2011 |
| Medium | Observational/cross-sectional | 6 | Briggs2008, de Nazelle2012, Dons2012, Dons2013, Morabia2009, Nyhan2013 |
| Medium | Quantitative modeling | 4 | de Nazelle2009, Gordon2012, Maizlish2013, Rabl2012 |
| Medium | Literature review | 1 | Giles2014 |
| Low | Case studies or small sample size | 1 | Gulliver2004 |
| Low | Expert opinion, best practice, gray literature | 1 | Figliozzi2012 |

| Exposure to pollutants: morbidity and mortality | | Transit |
|---|---|---|
| **There is very strong evidence that pollution from transportation sources is harmful to health.** | | |
| **Description of evidence base** | We reviewed 49 studies suggesting that transportation emissions harm health. These studies show consistent results and large effect sizes, and many have high-quality longitudinal or experimental designs. Major scientific agencies — including the CDC, EPA, WHO and American Heart Association — consider there is a causal relationship between auto emissions and health. | |
| **Remaining uncertainties** | We know that, broadly speaking, vehicle pollutants are harmful to health and that distance to high-traffic areas is a significant health risk. We have less information about acute exposures by different travel modes due to uncertainty about microenvironments. There also remains uncertainty about mechanisms by which air pollution harms health including which pollutant(s) result in specific health outcomes. | |
| **Assessment of confidence** | Very strong | |

| Evidence reviewed: exposure to pollutants — morbidity and mortality | | | Transit |
|---|---|---|---|
| **Quality** | **Description** | **Count** | **Reference list** |
| High | Longitudinal/controlled experimental study | 18 | Baleen2014a, Baleen2014b, Brunekreef2009, Chen2013, Dimakopoulou2014, Caiazzo2013, Gan2012, Gauderman2004, Hart2013, Hennig2014, Hoffmann2005, Hoffmann2007, Hoffmann2009a, Kälsch2014, Lepeule2012, Pope2009, Sørensen2012, Vineis2007 |
| High | Systematic review/meta-analysis | 6 | Brook2010, Chen2008, Janssen2011, Meng2013, WHO2003, WHO2013 |
| Medium | Observational/cross-sectional | 15 | Fuks2011, Hoffman2006, Hoffmann2009b, Kim2008, Lui2014, McConnell2006, McCreanor2007, Morabia2009, Nwokoro2012, Peters2013, Spira-Cohen2011, Strak2010, vanKempen2012b, Weichenthal2011, Zuurbier2010 |
| Medium | Quantitative modeling | 4 | MacMillan2014, Maizlish2013, Xia2013, Zhang2013 |
| Medium | Literature review | 5 | Brugge2007, Gold2013, Hofmann2011, Kelishadi2011, Laumbach2010 |
| Low | Case studies or small sample size | | |
| Low | Expert opinion, best practice, gray literature | 1 | Forastiere2013 |

| Noise | Transit |
|---|---|
| **There is moderate evidence that traffic noise disproportionately affects users.** | |
| **Description of evidence base** | Traffic noise is associated with negative health outcomes (see below). Very few studies specifically examine transit noise experienced by passengers. We reviewed 13 studies investigating traffic noise exposure, and four specific to transit. Whereas other traffic noise studies focus on broader health effects, transit noise is loud enough to directly affect hearing. Two studies that objectively measured transit noise found levels well above the threshold at which hearing loss is considered possible. More studies on this could influence our conclusion about this relationship. |
| **Remaining uncertainties** | Studies of occupational conditions consider noise exposure for operators of transit, but these typically focus on periods much longer than a typical transit journey. |
| **Assessment of confidence** | Moderate |

| Evidence reviewed: noise | | | Transit |
|---|---|---|---|
| **Quality** | **Description** | **Count** | **Reference list** |
| High | Longitudinal/controlled experimental study | | |
| High | Systematic review/meta-analysis | | |
| Medium | Observational/cross-sectional | 7 | Boogaard2009,Fuks2011, Gershon2013, Neitzel2012, Neitzel2009, Sorensen2013, Sorensen2012 |
| Medium | Quantitative modeling | 2 | Hammer2013, Seto2007 |
| Medium | Literature review | 3 | Babisch2006, Goines2007, Passchier-Vermeer2000 |
| Low | Case studies or small sample size | 1 | Dinno2011 |
| Low | Expert opinion, best practice, gray literature | | |

| Noise – morbidity and mortality | Transit |
|---|---|
| **There is very strong evidence that traffic noise is harmful to health.** | |
| **Description of evidence base** | We reviewed 43 studies linking morbidity and mortality to traffic noise exposure. These studies had consistent results and moderate effect sizes that seem to hold even when controlling for air pollution exposure. One of the strongest associations was between noise and myocardial infarction and/or hypertension with additional evidence of risk of diabetes and negative cognitive consequences for children. The literature draws heavily from residential exposure, implying long-term exposure, particularly at night. |
| **Remaining uncertainties** | Most noise studies are not specific to active transportation and many are from long-term rather than short-term exposure, making it difficult to generalize.<br><br>Noise and air pollution are highly correlated. While Gan2012, Kalsch2014, Sørensen2012 and other studies are suggestive of independent effects, future research is needed to understand the confounding relationship.<br><br>One branch of the traffic noise literature clearly describes annoyance as a result of exposure to traffic exposure. Annoyance seems to heighten negative health effects, likely through stress response, but the link between annoyance and other health outcomes could be more solid.<br><br>Threshold and dose-response are starting to be reported, but additional research is needed to fine-tune each. |
| **Assessment of confidence** | Strong |

| Evidence reviewed: noise | | | Transit |
|---|---|---|---|
| **Quality** | **Description** | **Count** | **Reference list** |
| High | Longitudinal/controlled experimental study | 8 | Kälsch2014, Gan2012, Hart2013, Notbohm2013, Sørensen2011, Sørensen2012, Sørensen2013, Sørensen2014 |
| High | Systematic review/meta-analysis | 7 | Babisch2008, Babisch2014, Ndrepepa2011, Tetreault2013, Tomei2010, vanKempen2012a, WHO2011 |

| Evidence reviewed: noise *(continued)* | | | Transit |
|---|---|---|---|
| **Quality** | **Description** | **Count** | **Reference list** |
| Medium | Observational/cross-sectional | 13 | Babisch2013, Banerjee2013, Birk2011, Chang2014, de Kluizenaar2013, Floud2013, Foraster2011, Fuks2011, Haralabidis2011, Liu2013, Liu2014, Huang2013, Kraus2013 |
| Medium | Literature review | 11 | Basner2014, Davies2012, Goins2007, Hammer2014, Kelishadi2011, Muenzel2014, Muzet2007, Pirrera2010, Seidman2010, vanCamp2013, vanKempen2012b |
| Medium | Quantitative modeling | 1 | Harding2013 |
| Low | Case studies or small sample size | | |
| Low | Expert opinion, best practice, gray literature | 3 | Kairns2014, Foraster2013, Holzman2014 |

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