

Using the daylight savings clock change to show ambient light conditions significantly influence active travel



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ABSTRACT

This article reports a novel procedure used to investigate whether ambient light conditions affect the number of people who choose to walk or cycle. Pedestrian and cyclist count data were analysed using the biannual daylight-saving clock changes to compare daylight and after-dark conditions whilst keeping seasonal and time-of-day factors constant. Changes in frequencies during a 1-h case period before and after a clock change, when light conditions varied significantly between daylight and darkness, were compared against control periods when the light condition did not change. Odds ratios indicated the numbers of pedestrians and cyclists during the case period were significantly higher during daylight conditions than after-dark, resulting in a 62% increase in pedestrians and a 38% increase in cyclists. These results show the importance of light conditions on the numbers of pedestrian and cyclists, and highlight the potential of road lighting as a policy measure to encourage active travel after-dark.

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1. Introduction

Encouraging the use of active travel methods such as walking and cycling has a number of benefits. These include improvements in health outcomes such as all-cause mortality (Kelly et al., 2014), obesity (Pucher, Buehler, Bassett, & Dannenberg, 2010) and other health-related measures such as cancer rates and cardiovascular fitness (Oja et al., 2011). Such health improvements can lead to economic benefits (Jarrett et al., 2012). The promotion of active travel can also lead to reductions in the use of motorised transport (Ogilvie, Egan, Hamilton, & Petticrew, 2004), with reductions in CO₂ emissions and improvements in air quality as a result (Goodman, Brand, & Ogilvie, 2012; Grabow et al., 2012; Rissel, 2009). Citizens who continue to use their vehicles for transport may also benefit from the promotion of active transport, due to reduced congestion on roads.

One of the key purposes of road lighting is to create acceptable conditions for people to walk or cycle after-dark (British Standards Institution, 2012), thus encouraging active travel. For example, Kerr et al. (2016) and Giehl, Hallal, Brownson & d'Orsi (2016) both found

that road lighting was positively associated with increased walking. Cervero and Kockelman (1997) also suggested that the presence of road lighting and the distance between lamps were significant aspects of neighbourhood design that contributed to encouraging non-automobile travel. Differences in lighting conditions can lead to changes in behaviour. For example, Painter (1994; 1996) found there was an increase in pedestrian use of a crime hotspot after new lighting was installed. Light conditions can also influence the speed with which pedestrians walk (Donker, Kruisheer & Kooi, 2011). Cyclists, as well as pedestrians, are also likely to be influenced by light conditions. For example, the ability to make a trip during daylight hours was found to be one of the top ten motivations in deciding to cycle, whilst using a route that was not well lit after-dark was one of the top ten deterrents (Winters, Davidson, Kao, & Teschke, 2011).

There are several reasons why good light conditions may encourage walking or cycling. First, it allows obstacles and trip hazards to be seen and avoided, and this is a critical task for both pedestrians and cyclists (Fotios, Uttley, Cheal, & Hara, 2015; Vansteenkiste, Cardon, D'Hondt, Philippaerts, & Lenoir, 2013). Lighting characteristics such as illuminance and spectrum can influence the ability of a pedestrian or cyclist to detect an obstacle in the path in front of them (Fotios, Qasem, Cheal, & Uttley, 2016; Uttley, Fotios, & Cheal, 2015) and this may make a person more or less likely to walk or cycle, depending on the light conditions. Second, it may make the pedestrian or cyclist feel safer and less

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threatened (Boyce, Eklund, Hamilton, & Bruno, 2000; Fotios, Unwin, & Farrall, 2015). Good light conditions are required to allow a pedestrian or cyclist to see far ahead and have an open view. This is one of the three key attributes an area requires to make it feel safe (prospect, refuge and escape, Fisher & Nasar, 1992). The prospect of an area will be at its highest during daylight, but reductions to this after-dark can be mitigated by road lighting. For example Boyce et al. (2000) asked participants to rate how safe they felt at a number of parking lots in the US during daylight and after-dark. Safety ratings were generally lower after-dark than during daylight, but the difference reduced as the illuminance at the parking lot increased. Feeling safe is particularly important for pedestrians as perceptions of neighbourhood safety have been shown to influence walking levels in that neighbourhood (Foster et al., 2016; Mason, Kearns, & Livingston, 2013). The third and final reason why light conditions may influence the decision of a person to walk or cycle is due to their perceived visibility. Daylight or road lighting may make the pedestrian or cyclist feel more visible and less at risk of being hit by a vehicle as the rate and severity of traffic collisions involving pedestrians and cyclists is increased when there is poor or no road lighting (Eluru, Bhat, & Hensher, 2008), and during darkness (Johansson, Wanvik, & Elvik, 2009; Twisk & Reurings, 2013).

These three factors of obstacle avoidance, perceived safety and perceived visibility suggest light should influence the decision of potential pedestrians and cyclists to travel or not and there should be a link between frequency of active travellers and light conditions. A causal connection between light and active travel has not been shown however. For example, previous work has linked the presence of road lighting with increased walking but it is not clear whether this is due to the light conditions provided or some other factor. This uncertainty is compounded by the fact that previous research related to this question has tended to use subjective methods for assessing the role of lighting, a good example of this being literature on lighting and perceived safety. A common approach is to ask participants to rate how safe they feel under different light conditions using a category rating response scale (Boomsma & Steg, 2012; Loewen, Steel, & Suedfeld, 1993; Rea, Bullough, & Brons, 2015). This approach has some limitations, if not carried out in a systematic way (Fotios & Castleton, 2016; Fotios, 2016). For example, asking for a rating compels a participant to make an assessment of something they perhaps would not otherwise consider relevant (Fotios, Unwin, et al., 2015). Data collected using subjective rating scales may be prone to range bias (Poulton, 1989) and influenced by the phrasing of the question (Schwarz, 1999). Perhaps most significantly, it is not certain that a subjective response by a participant translates into actual behaviour. For example, if light conditions do influence the subjective assessment of safety this may not necessarily be reflected in actual walking and cycling behaviour. Previous research has linked lighting conditions, perceived safety and physical activity (e.g. Weber, Hallal, Xavier, Jayce, & D'Orsi, 2012), but this has been based on subjective responses and is subject to the limitations outlined previously. Objective measures of behaviour could provide stronger evidence.

In the current article we present an alternative procedure to examine whether the amount of ambient light affects the number of pedestrians and cyclists, which is to count the number of pedestrians and cyclists passing a location in the periods immediately before and after daylight savings clock change. This was inspired by the investigation of vehicle collisions reported by Sullivan and Flannagan (Sullivan & Flannagan, 2002).

There are a range of factors that influence the volume of pedestrians and cyclists other than the light conditions, two of the most important being the season and the time of day (Aultman-Hall, Lane, & Lambert, 2009). The biannual changes to clock times

resulting from daylight saving time provide an opportunity to control these two variables whilst changing the ambient light condition. This is where clock times in Northern hemisphere countries are advanced in Spring and moved back in Autumn by 1 h, changing the time of day at which dawn and dusk occur. This means that, as an example, a walk to or from work could take place during daylight in one week but after-dark the following week, at the same time of day. That is, an abrupt change of light level for the same journey decision. Counting the number of pedestrians and cyclists passing a particular location at this time of day means that the effect of light on the decision to walk is isolated from potential confounds of journey purpose, destination and environment. A similar approach utilising the daylight savings clock changes was used by Sullivan and Flannagan (2002). They analysed vehicle crash statistics in the US between 1987 and 1997. Their aim was to determine the likely effectiveness of adaptive headlamps in different driving situations, by identifying when dark conditions significantly increased the crash risk compared with daylight. They compared crash frequencies in the nine weeks before and after a clock change to see what the effect of the abrupt change in light conditions was. We use a similar before and after clock change method to compare daylight and dark conditions and their effect on active traveller frequencies. We develop this method further by introducing control periods in which light conditions do not change, against which changes between daylight and dark conditions can be compared.

Pedestrian and cyclist count data collected over a five year period from the Arlington County area of Virginia state, United States, have been analysed using this daylight saving clock change method. Frequencies during a case hour before and after the Spring and Autumn clock changes are compared relative to changes in control periods in which the light conditions do not change.

2. Method

2.1. Arlington pedestrian and cyclist counters

Automated pedestrian and cyclist counters have been installed in a number of locations within Arlington County, Virginia, in the Washington, DC metropolitan area, since October 2009, on both cycle trails and on-street cycle lanes. Arlington County is a 26 square mile area that was formerly an inner ring suburb of Washington DC. Walking and cycling have been regarded as important complements to rail and bus transit by the Local Authority, and led to the development of a healthy active travel infrastructure, matched by investment in active travel count apparatus to support transport planning. By 2016 there were 10 cyclist-only counters and 19 joint pedestrian and cyclist counters. Examples of these counters are shown in Fig. 1. The counters continuously record pedestrian and cyclist volumes and this data is available down to 15-min aggregations via a web service at the Bike Arlington website (<http://www.bikearlington.com/pages/biking-in-arlington/counting-bikes-to-plan-for-bikes/data-for-developers/>). Separate data for pedestrians and cyclists are provided. The direction of the traveller is also provided, as 'inbound' or 'outbound' relative to the centre of the Arlington area: for the analysis presented in this paper, inbound and outbound volumes were combined.

2.2. Data collation

The dates of Spring and Autumn daylight saving clock changes in the US between November 2011 and March 2016 are given in Table 1. An appropriate 1-h light transition period was identified for each of the clock-change periods, such that it was dark during this hour one side of the clock change date and daylight during the



Fig. 1. Example images of pedestrian and bike counters. Left: Custis Rosslyn, bike and pedestrian counter; Right: Crystal Drive North, bike-only counter.

same hour on the other side of the clock change. These times were identified using the sunset times given for the Washington DC area by the Time and Date website (Time and Date, 2016). This period was defined as the case period. In addition, two 1-h control periods were identified, these having the same light condition both before and after the clock change for the same 1-h period. One of these was 1.5 h before the case period, ensuring it was daylight both before and after the clock change. The other was 1.5 h after the case period, ensuring it was dark both before and after the clock change. Two further control periods were also identified, these being 3.5 h before or after the case period, and also having the same light condition either side of the clock change. Multiple control periods were selected because estimates of the effect of the transition in light conditions may depend on the choice of the comparison, control hour. It is possible that any changes in frequencies during these control periods could vary systematically with the time of day (Johansson et al., 2009). As an example, it is possible that the hypothesised effect of the transition in light conditions during the case period could have a spillover effect on nearby times. The decision to walk or cycle may be influenced by the knowledge that there would be more (or less) daylight in the evening after the clock change, even if the person ended up walking or cycling in the control period rather than the case period. One way to test this hypothesis is to compare frequencies in the case period with control periods that are closer or further away in time from the case period. People who are walking or cycling during a 1-h period that is a greater temporal distance from the case period may be less likely to have been influenced in their decision to walk/cycle by the

transition in ambient light levels, compared with someone walking/cycling during an hour that is temporally closer to the case period. The hours selected for all case and control periods are given in Table 2.

Data for the case and control periods were extracted for the 13 days (Monday of week one to Saturday of week two) before and after the clock change dates given in Table 1, for all available counters. The day of the actual clock change (always a Sunday) was not included. These data were cleaned and checked for anomalous data. This included removing data for one counter that provided combined pedestrian and cyclist data without distinguishing between the two. Outlying data was identified by converting daily counts within each 1-h period into modified z-scores using the median absolute deviation, as recommended by Leys, Ley, Klein, Bernard, and Licata (2013). Daily counts with z-scores greater than ± 3.5 were excluded from the final dataset, following recommendations by Iglewicz and Hoaglin (1993). This resulted in the exclusion of 1.6% of daily count data.

Data were incomplete or missing entirely for some counters, due to them either not being installed by the dates queried, the counter being offline as a result of damage or routine maintenance, or the removal of outlying data. Counters that had less than 3 days of data in either the weeks before or after the clock change date were excluded. This process resulted in data from 11 counters being included from November 2011 up to 36 counters from March 2016, as new counters were installed during this period. This represented between 67% and 92% of all installed counters in any given season

Table 1
Dates of Spring and Autumn daylight saving clock changes between November 2011 and March 2016. In Spring clocks move forward 1 h, in Autumn they move backwards 1 h.

Year	Spring	Autumn
2011	Not included	6 November
2012	11 March	4 November
2013	10 March	3 November
2014	9 March	2 November
2015	8 March	1 November
2016	13 March	Not included

Table 2
One-hour time slots for case and control periods at Spring and Autumn daylight saving clock changes.

Period	Spring	Autumn	Light before/after clock change
Case	18:00–19:00	17:00–18:00	Dark – Day (Spring) Day – Dark (Autumn)
Day Control	16:30–17:30	15:30–16:30	Day – Day (Spring & Autumn)
Dark Control	19:30–20:30	18:30–19:30	Dark – Dark (Spring & Autumn)
Early Day Control	14:30–15:30	13:30–14:30	Day – Day (Spring & Autumn)
Late Dark Control	21:30–22:30	20:30–21:30	Dark – Dark (Spring & Autumn)

Table 3
Number of counters and daily counts included in final dataset, following data cleaning.

Year	Clock change time	Number of counters included in final dataset ^a		Minimum – Maximum number of daily counts ^b		Number of counters in each location type	
		Pedestrians	Cyclists	Pedestrians	Cyclists	On-street cycle lanes	Cycle trails
2011	Autumn	9	11	117–117	143–143	0	11
2012	Spring	8	9	104–113	90–126	0	9
	Autumn	8	9	104–130	117–143	0	9
2013	Spring	12	22	65–140	182–263	9	13
	Autumn	5	15	156–156	286–286	8	7
2014	Spring	12	21	168–181	262–298	8	13
	Autumn	13	22	133–171	237–281	8	14
2015	Spring	17	27	234–270	381–439	10	17
	Autumn	19	31	195–221	299–372	11	20
2016	Spring	22	33	286–323	416–462	10	23

^a Note that many of the counters included in the final dataset record both pedestrians and cyclists. No counters record only pedestrians, although some counters record only cyclists.

^b Minimum and maximum daily counts are shown as there is some variation between the 1-h case and control periods, depending on missing data for these different times of the day.

and year. Completeness of data was good, with only 6.0% of included counters for any particular 1-h period before or after the clock change having less than the full 13 days of data. Table 3 shows details of the number and types of counters that were included in the final dataset, and the minimum number of daily counts for pedestrians and cyclists, at each clock change time and year.

3. Results

3.1. Overall results

The mean daily count across all years was calculated for all counters at each of the 1-h case and control periods. Table 4 shows the overall means and standard deviations across all counters for each of the 1-h time periods that data was extracted for. Fig. 2 shows the overall ratio between cyclist and pedestrian frequencies in the case hour and control hours, over the 13 days before and after the biannual clock changes. This shows the direction of change in the frequencies following Spring and Autumn clock changes, highlighting how there is an increase when the case hour is in daylight rather than darkness, relative to changes in the control hours. It is also apparent that this effect appears larger for the Autumn clock change compared with the Spring clock change.

Following the method outlined in Johansson et al. (2009), an odds ratio and associated 95% confidence intervals were calculated separately for pedestrian and cyclist frequencies, comparing changes before and after a clock change in the case period with each of the four control periods. The odds ratios were calculated using Equation (1) or Equation (2), depending on whether the clock change was in the Spring or Autumn. The transition in light conditions during the case period could either be from dark to daylight

(Spring, clocks go forward) or daylight to dark (Autumn, clocks go backward). The numerators and denominators in Equation (1) were therefore reversed for Autumn clock changes, so that any relative increase in numbers during daylight conditions would be reflected by an odds ratio greater than one. The odds ratios for Spring clock changes were calculated using Equation (1), the odds ratios for Autumn clock changes were calculated using Equation (2). Odds ratios and their associated confidence intervals are themselves indications of effect size, but for reference it may be useful to note that odds ratios of 1.22, 1.86 and 3.00 have been equated to Cohen's small, medium and large effect sizes (Cohen, 1992; Olivier & Bell, 2013).

$$Odds\ ratio = \frac{\left(\frac{Frequency\ during\ experimental\ period\ after\ clock\ change}{Frequency\ during\ experimental\ period\ before\ clock\ change} \right)}{\left(\frac{Frequency\ during\ control\ period\ after\ clock\ change}{Frequency\ during\ control\ period\ before\ clock\ change} \right)} \tag{1}$$

$$Odds\ ratio = \frac{\left(\frac{Frequency\ during\ experimental\ period\ before\ clock\ change}{Frequency\ during\ experimental\ period\ after\ clock\ change} \right)}{\left(\frac{Frequency\ during\ control\ period\ before\ clock\ change}{Frequency\ during\ control\ period\ after\ clock\ change} \right)} \tag{2}$$

The calculated odds ratios and 95% confidence intervals comparing each of the four control periods against the case period are shown in Fig. 3. All odds ratios were significantly greater than one, indicating that the numbers of pedestrians and cyclists were significantly higher during the daylight side of the clock change in the case period compared with the after-dark side and that this

Table 4
Overall mean daily pedestrian and cyclist counts for 1-h case and control periods, averaged across all counters and years. Means for period when case hour was in daylight or darkness are shown.

One-hour time period	Overall mean daily count per counter (standard deviation)			
	Pedestrians		Cyclists	
	Case period in daylight ^a	Case period in darkness ^a	Case period in daylight ^a	Case period in darkness ^a
Case period	65 (±59)	40 (±54)	64 (±62)	41 (±66)
Day Control	51 (±48)	52 (±77)	51 (±44)	43 (±61)
Dark Control	24 (±34)	16 (±28)	18 (±20)	15 (±22)
Early Day Control	37 (±31)	38 (±44)	28 (±23)	25 (±34)
Late Dark Control	8 (±15)	7 (±17)	5 (±6)	4 (±9)

^a Case period in daylight after clock change in Spring, before clock change in Autumn. Case period in darkness before clock change in Spring, after clock change in Autumn.

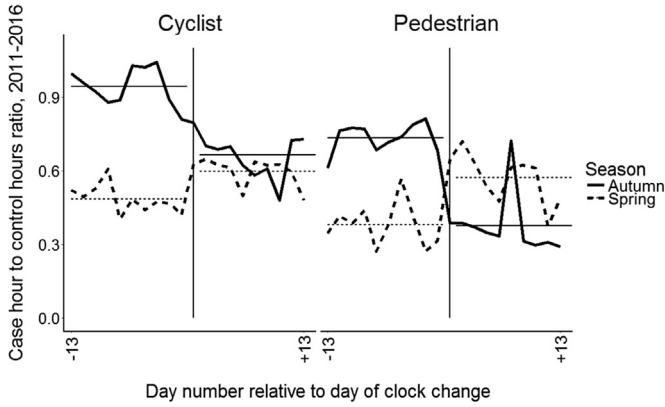


Fig. 2. Ratio of traveller counts during case hour compared with control hours, per day. Horizontal lines show mean ratio each day before and after clock change. Vertical line indicates day of clock change.

increase was more than that seen in all four control periods. The odds ratios were significantly higher for pedestrians than cyclists for three of the four control periods, with the Dark Control period being the exception. This suggests the transition between darkness and daylight during the case period may have had a greater effect on the numbers of pedestrians than on the numbers of cyclists. The overall odds ratio when all control periods are combined is 1.38 (1.37–1.39 95% CI, $p < 0.001$) for cyclists and 1.62 (1.60–1.63 95% CI, $p < 0.001$) for pedestrians.

3.2. Location type

For cyclists, frequency data were collected from two types of locations – on-street cycle lanes, and cycle trails that are not associated with a road. The split in number of counters for each of these location types between 2011 and 2016 is shown in Table 3. Fig. 4 compares the odds ratios of cyclist frequencies during daylight compared with dark at on-street cycle lane and cycle trail locations. Pedestrian frequencies are not compared as the on-street cycle lanes only recorded data about cyclists. The odds ratios for both on-street cycle lanes and cycle trails are significantly greater than one for all control period comparisons. However, odds ratios for the cycle trails are also significantly higher than for the on-street cycle lanes for all four control periods. This suggests the effect of the transition between darkness and daylight during the

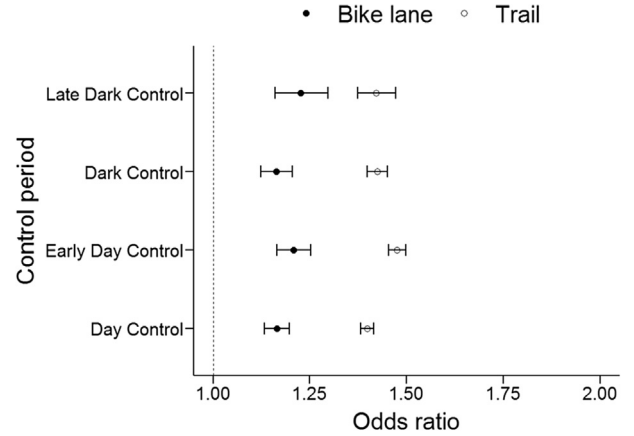


Fig. 4. Odds ratios of increase in cyclist frequencies at on-street cycle lanes or cycle trails during daylight compared with dark, relative to control periods. Error bars show 95% confidence intervals at $p = 0.05$.

case period had a greater effect on cyclist frequencies at trail locations, compared with cycle lane locations.

3.3. Weather

3.3.1. Temperature

The analysis method reported in this paper of comparing active traveller frequencies before and after a daylight saving clock change attempts to isolate the effect of ambient light conditions on the presence of cyclists and pedestrians by comparing the same hour of the day during daylight and after-dark conditions. Although the comparison periods before and after the clock change are contiguous it is possible that weather conditions were not the same, introducing a potential confound. Furthermore, the temperature may have varied systematically, as the daylight period always fell in the part of the year expected to be warmer compared with the after-dark period. For example, in Spring when the clocks move forward 1 h, the after-dark condition in the case period falls before the clock change, in the earlier part of the year when it may be expected to be slightly cooler in temperature. In Autumn, when clocks move backward 1 h, the reverse situation occurs, with the after-dark condition falling after the clock change, as temperatures may be expected to be cooling. Therefore, the after-dark condition may systematically be cooler than the daylight condition. As temperature is a significant factor in whether someone chooses to walk or cycle (e.g. Miranda-Moreno & Nosal, 2011; Saneinejad, Roorda, & Kennedy, 2012) this would provide an alternative explanation for why the daylight condition shows a relative increase in pedestrians and cyclists.

To explore this alternative explanation temperature data for the Arlington area of the United States was downloaded from the Weather Underground via the web service provided at the Bike Arlington website (<http://www.bikearlington.com/pages/biking-in-arlington/counting-bikes-to-plan-for-bikes/data-for-developers/>). Hourly data was extracted for each of the 1-h case and control periods (see Table 2), during the two-week periods before and after each clock change between Autumn 2011 and Spring 2016. The hourly temperature data was averaged to give a mean temperature for each day. Fig. 5 shows the overall mean daily temperature combined across all years, for the day and after-dark periods in Spring and Autumn clock changes.

Fig. 5 suggests mean temperatures were higher during the daylight period compared with the dark period, for both Autumn and Spring clock changes. This was confirmed with a 2-way

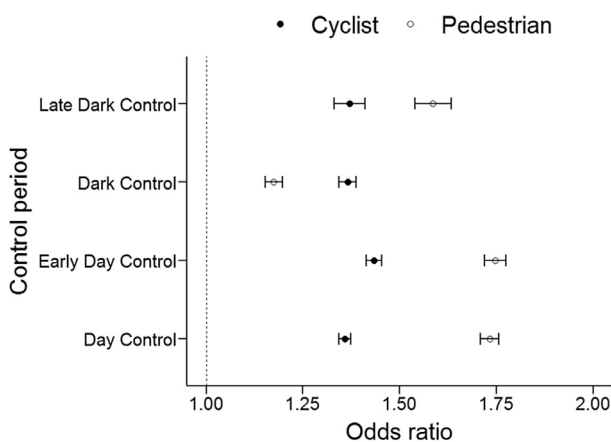


Fig. 3. Odds ratios of increase in cyclist and pedestrian frequencies during daylight compared with dark, relative to control periods. Error bars show 95% confidence intervals at $p = 0.05$.

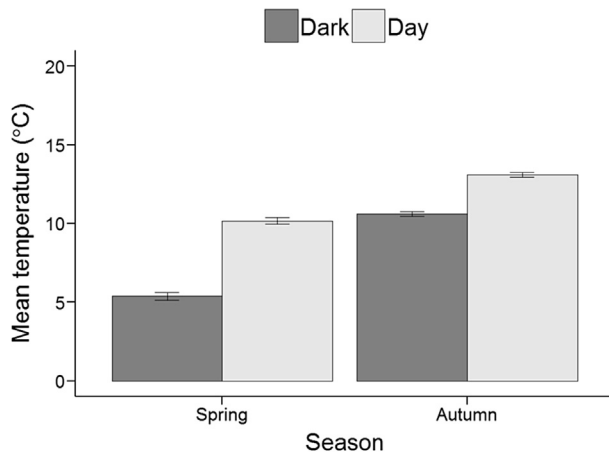


Fig. 5. Mean daily temperature (°C) during the two-week 'dark' or 'daylight' period for Spring and Autumn clock changes. Dark condition represents the period before the clock change at Spring clock changes and after the clock change at Autumn clock changes, and vice versa for Day conditions. Error bars show Standard Error of the Mean.

between-subjects ANOVA, with the clock change season and the ambient light condition as independent factors. There was a significant main effect of the light condition with mean temperatures significantly higher during daylight periods (mean = 11.6 °C) than after-dark periods (mean = 8.1 °C, $F(1,285) = 40.8$, $p < 0.001$, $\eta_p^2 = 0.13$). There was also a significant main effect of the clock change season, with mean temperatures significantly higher at the Autumn clock change (mean = 11.8 °C) than the Spring clock change (mean = 7.8 °C, $F(1,285) = 55.5$, $p < 0.001$, $\eta_p^2 = 0.16$).

These results show that temperature did significantly differ between the before and after clock change periods, with higher temperatures during those periods in the ambient daylight condition than in the ambient darkness condition. However, to confirm whether the change in light conditions can still explain the change in pedestrian and cyclist frequencies demonstrated in section 3.1, differences in temperature were tested before and after every clock change individually, to determine if in some years the temperature did not significantly change. If such years and seasons were found, these could be used to determine whether a change in pedestrian and cyclist numbers was still seen. If this was the case, it would suggest the light condition was an explanatory factor even when temperature remained constant before and after the clock change. A series of independent t-tests were carried out comparing temperatures during the day and after-dark periods for each clock change in each year. Bonferroni correction was applied to account for the multiple testing, giving an alpha of $0.05/10 = 0.005$. The results are summarised in Table 5.

These tests suggest there were five occasions when temperatures did not differ in the two week periods before and after clock changes (Autumn 2011; Spring 2013; Autumn 2013, Autumn 2015 and Spring 2016). One of these occasions (Autumn 2013) did show a relatively large difference in temperatures and was close to reaching the Bonferroni-corrected alpha level ($p = 0.007$), and is therefore not included as an occasion when temperatures did not differ, to err on the side of caution. The other four occasions are deemed to not show a change in temperature before and after the clock change.

Clock changes that did not show a significant change in temperature before and after the change date were combined and odds ratios were calculated comparing the case period with each of the four control periods. The same was done for clock changes that did show a significant change in temperature. The calculated odds ratios and 95% confidence intervals are shown in Fig. 6.

The data shown in Fig. 6 demonstrate that even when changes in temperature are accounted for and only occasions when the temperature did not significantly change before and after the clock change are examined, the odds ratios are still significantly above one. This suggests the effect of the transition in ambient light condition alone can explain the increase in pedestrians and cyclists during the daylight periods independently from any influence of temperature. In fact, the clock changes that showed no change in temperature generally produced larger odds ratios than those clock changes where the temperature did change significantly. This would suggest the effect of the transition in light conditions was larger when there was no temperature change.

3.3.2. Precipitation

It is possible that precipitation may also influence the decision to walk or cycle (de Montigny, Ling & Zaccarolis, 2012; Nosal & Miranda-Moreno, 2014) and thus confound explanation of the change in pedestrian and cyclist numbers. To check this, daily precipitation levels were obtained from the Weather Underground service via the Bike Arlington website, with mean daily precipitation calculated for the periods before and after each clock change. A two-way between-subjects ANOVA was carried out, with the clock change season and ambient light condition as independent factors, to identify any systematic differences in precipitation levels. This suggested there was no difference in precipitation volume between the Spring and Autumn seasons (respective means = 0.09 and 0.11 inches per day, $F(1,231) < 0.001$, $p = 0.98$). There was also no difference in precipitation volumes between the daylight and dark periods (respective means = 0.12 and 0.08 inches per day, $F(1,231) = 0.77$, $p = 0.38$). There was also no interaction between the season and the ambient light condition ($F(1,231) = 2.91$, $p = 0.09$). These results do not suggest systematic variations in precipitation levels between the periods when the case hour was in daylight and in darkness and precipitation can therefore be ruled out as a

Table 5
Comparison of mean daily temperatures in dark and day periods for each clock change between Autumn 2011 and Spring 2016.

Year	Clock Change Season	Dark period mean temperature (°C)	Day period mean temperature (°C)	Significance of difference (p-value)
2011	Autumn	10.9	10.5	0.74
2012	Spring	8.9	16.3	<0.001 ^a
	Autumn	8.3	13.6	0.002 ^a
2013	Spring	5.4	6.6	0.23
	Autumn	9.4	12.9	0.007
2014	Spring	1.7	7.5	0.003 ^a
	Autumn	10.5	14.9	0.001 ^a
2015	Spring	0.3	8.8	<0.001 ^a
	Autumn	13.9	13.4	0.74
2016	Spring	10.6	12.1	0.47

^a Temperatures are significantly different at Bonferroni-corrected alpha level of 0.005.

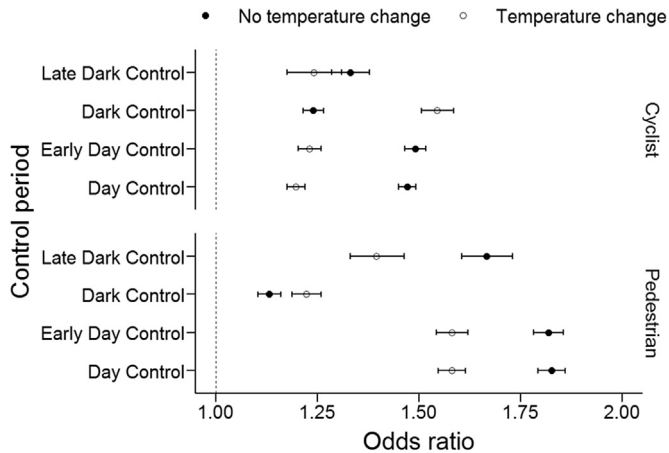


Fig. 6. Odds ratios of increase in cyclist and pedestrian frequencies during daylight compared with dark, relative to control periods, for clock changes that did and did not show a significant change in temperature. Error bars show 95% confidence intervals at $p = 0.05$.

potential explanation for the differences found in pedestrian and cyclist frequencies when the ambient light condition changed.

4. Discussion

The aim of this work was to establish whether ambient light level affects the number of people choosing to walk or cycle. A large number of pedestrian and cyclist counters in Arlington County, Virginia, provided extensive data about the numbers of people walking and cycling. This open-source data provided the opportunity to carry out a novel method of analysis using the daylight-saving clock change to isolate the effect of an abrupt change in ambient light conditions. Data was extracted for two-week periods before and after ten clock-change dates between Autumn 2011 and Spring 2016. Pedestrian and cyclist frequencies during a 1-h 'case' time period, in which the ambient light conditions were different before and after the clock change, were compared against four other 1-h 'control' periods, in which the ambient light conditions remained the same both before and after the clock change. Two of these control periods were chosen to be close in time to the case period, one during daylight the other after-dark. The other two control periods were chosen to be more distant in time from the case period. When all control periods were combined, the calculated odds ratio suggested daylight conditions resulted in a 62% increase in pedestrians and a 38% increase in cyclists, compared with after-dark conditions.

Looking separately at the odds ratios for each of the four control periods, there is a suggestion that the effect of the transition between darkness and daylight in the case period was greater when compared against the control periods that were further away in time, than when compared against the control periods that were nearer in time to the case period's hour of transition. This is confirmed when looking at odds ratios for the near control periods combined (Dark Control and Day Control) and the far control periods combined (Late Dark Control and Early Day Control). For pedestrians, the combined odds ratio for the near control periods was 1.56 (1.54–1.58 95% CI) compared with 1.72 (1.69–1.75 95% CI) for the far control periods. For cyclists, the combined odds ratio for the near control periods was 1.36 (1.35–1.37 95% CI) compared with 1.42 (1.41–1.44 95% CI) for the far control periods. This suggests the odds ratios were significantly greater for the far control periods than the near control periods, for both pedestrians and cyclists. This supports the

hypothesis that there is some spillover or displacement effect of the transition in ambient light conditions. This may also partly explain why the OR for pedestrians is smaller than for cyclists when using the dark control hour, but for the other three control periods the pedestrian OR is larger than the cyclist OR (see Fig. 3). This reversal in the size of OR for pedestrians and cyclists is due to a relatively large change in pedestrians during the dark control period when the case hour is in daylight compared with darkness (daily mean count = 24 and 16 respectively; see Table 2). The equivalent change in cyclists is smaller (daily mean count = 18 and 15 for dark control hour when case hour is in daylight and darkness respectively; see Table 2). This may be due to a greater spillover effect for pedestrians compared with cyclists. Possible reasons for this include reduced flexibility in work departure time amongst cyclist compared with pedestrian commuters due to considerations about road traffic volumes or the habitual nature of cycle commuting. There may also be increased opportunity for delays and detours during a pedestrian's journey home (e.g. visit to the shops or to a bar) compared with a cyclist's. Fig. 8 shows standardised hourly frequencies for pedestrians and cyclists during the 13 day periods before and after Spring and Autumn clock changes in 2015, as an illustration of daily patterns in pedestrian and cyclist numbers. There are large peaks in cyclist frequencies at morning and evening commuter times, and whether the case hour is in daylight or darkness does not alter the timing of these peaks. This supports the suggestion that cyclists may be quite rigid in their travel times, producing a relatively limited spillover effect. The travel times of pedestrians is a lot more distributed throughout the day however, with morning and evening peak times much less obvious compared to cyclists. This suggests there may be greater fluidity in travel times of pedestrians, potentially leading to a greater spillover of travelling during the dark control hour. Further data is needed to corroborate this hypothesis though.

The Arlington pedestrian and cyclist counters were located in two types of location – on-street cycle lanes, and cycle trails. The calculated odds ratios for cycle trail locations were significantly greater than on-street cycle lane locations for all four control periods (Fig. 3). This suggests the ambient light conditions had a greater effect on the number of cyclists on the cycle trails compared with the cycle lanes. One possible explanation for this is that the cycle lanes may be used more by cyclist commuters travelling to and from work. This journey is likely to be habitual and therefore the decision to cycle or not may be less likely to be influenced by the light conditions. The cycle trails are more likely to be used by recreational cyclists, who can be more selective in what days and times they choose to cycle, and the ambient light condition is likely to have a greater influence on whether such cyclists choose to cycle at a particular time. As a result, there may be less use of the cycle trails when dark, compared with the on-street cycle lanes, which would explain the larger odds ratios for cycle trails. The cycle trails and cycle lanes may also be located in areas of different land use, e.g. residential districts, parks, industrial areas, and this may influence the type of user and their propensity to travel at different times of the day and week. The users of the two types of cycle paths may also differ in their confidence in cycling and perceptions of danger. Cyclists who are more willing to cycle on urban roads and who see themselves as competent may be more likely to see cycling as a safe travel mode. This may result in cyclists who use the on-street cycle lanes being less influenced by the potential safety implications of cycling in darkness rather than daylight, compared with cyclists who use the cycle trails.

An alternative explanation for the difference between on-street cycle lanes and cycle trails though could relate to the public lighting that is present in these two types of locations. The on-street cycle

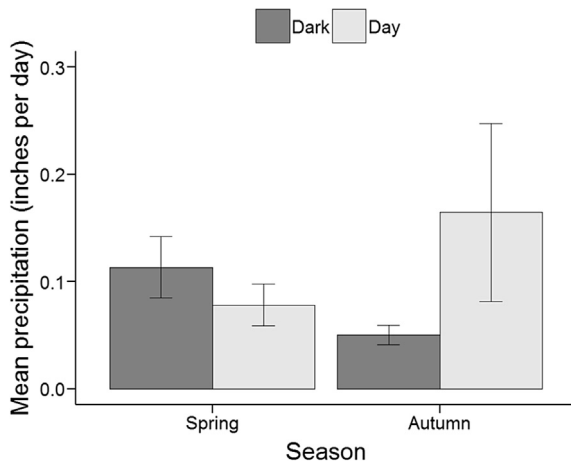


Fig. 7. Mean daily precipitation during the periods before and after clock changes, when case hour was in daylight or darkness, by season.

lanes are likely to have well-provisioned public road lighting as they are situated on roads used by motor vehicles. This may be less the case on cycle trails however, where the public lighting may be less frequent and dimmer, if present at all. For example, many of the cycle trails transect public parks, and these are frequently not lit after-dark. Greater provision of public lighting after-dark may result in more cyclists travelling after-dark, and this could explain why the effect of the transition between daylight and darkness is greater on cycle trails than on-street cycle lanes. The cycle lane and trail locations can be seen as typologically similar to an urban and rural distinction, with more road lighting at urban than rural locations. Johansson et al. (2009) suggested the reduced road lighting on rural roads may have accounted for their results about vehicle collisions, which showed larger odds ratios related to the effect of dark conditions on rural roads, compared with urban roads.

Weather conditions are an important consideration, alongside light levels, in determining whether someone chooses to walk or cycle (e.g. Saneinejad et al., 2012). In particular, temperature, as a relatively predictable and stable variable of climate, is likely to have an influence on active travelling. A limitation of the current approach using clock changes to investigate the effect of light conditions on active travel is that the period around the clock change date that had more daylight was also the period that was

likely to have slightly warmer temperatures, all things being equal. The 'daylight' side of the clock change had significantly warmer daily mean temperatures than the 'darkness' side of the clock change (Fig. 5). However, in some years the mean daily temperature did not change before and after the clock change. These occasions still showed odds ratios significantly greater than one, indicating that the transition in light had a significant effect on pedestrian and cyclist numbers, over and above any effect of temperature (Fig. 6). In fact, the effect was larger when there was no change in temperature, compared with when the temperature also increased during the daylight side of the clock change. This is logical – an increase in temperature may increase numbers in the control periods which will reduce the relative size of the effect of the transition in light when the case period is compared against the control periods. This is why the effect is larger at those clock change times when temperature did not significantly change before and after the clock change date. An increase in temperature serves to partially mask the effect of the transition in light. We also examined precipitation to determine whether this could explain the changes in active traveller counts, but found no difference in precipitation levels before and after the clock changes (see Fig. 7).

The 1-h clock change that occurs in the Spring and Autumn of each year is not only marked by an abrupt change in ambient light levels at the same time of the day, but may also be marked by individual behavioural and wider societal changes. For example, although we show that there is a change in the number of active travellers before and after a clock change even when temperature does not change, it is possible that the clock change represents a psychological Rubicon for many people that symbolises the onset of a new season. This may result in changes in behaviour, activity schedules or perceptions about the environment (such as it being warmer or colder) that may not reflect true changes. The transition to and from Daylight Saving Time may also be used by businesses, organisations and local services to change their hours of business. As an example, in our city of Sheffield, UK, household waste sites change between 'Summer' and 'Winter' opening times in April and October, around the time of the clock changes. Such changes could result in changes to the behaviour of local residents resulting in differences in the numbers of pedestrians and cyclists before and after a clock change. Clock changes can also cause changes to circadian rhythms and waking times (e.g. Kantermann, Juda, Merrow, & Roenneberg, 2007) which may influence behaviour. As an example of this, Daylight Saving Time has been associated with an increase in 'cyberloafing' behaviour amongst employees as a

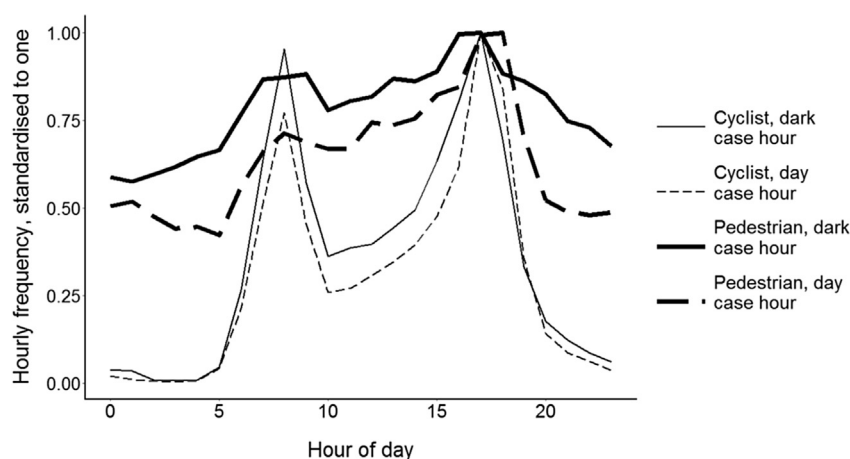


Fig. 8. Hourly frequency data for pedestrians and cyclists during the 13 day period before and after each clock change in 2015, standardised to maximum of one. Solid lines indicate period when case hour was in darkness, dashed lines indicate period when case hour was in daylight.

result of lost and low-quality sleep (Wagner, Barnes, Lim, & Ferris, 2012). Such behavioural changes may produce variations in the frequency of pedestrians and cyclists during the case hour examined in the current study.

Therefore a number of potential behavioural and societal changes could occur as a result of the biannual clock changes but are not overtly linked to changes in ambient light conditions. These may contribute towards changes in active traveller frequencies. Although the use of control hours in the present study attempts to account for such confounding factors that are unrelated to light conditions, further investigation is required to determine the exact influence of these behavioural and societal changes on pedestrian and cyclist numbers.

5. Conclusions

Active travel, i.e. walking and cycling, has a range of benefits and should be encouraged and facilitated whenever possible. A number of potential barriers to active travel exist, such as physical fitness, habitual behaviour or perceived environmental factors such as personal safety (e.g. Dawson, Hillsdon, Boller & Foster, 2007). One environmental factor that may be important is the light condition. We have shown that ambient light levels significantly influence the numbers of people choosing to walk or cycle. In drawing this conclusion we have accounted for seasonal and time-of-day factors, by using the daylight-saving clock change analysis method. To our knowledge, this is the first time this method has been used to examine active travel behaviour. We also show that light level is a significant determinant of active travel even when temperature is accounted for. The presence or absence of public lighting is also a possible explanation for why bigger reductions in active travellers were seen after-dark on cycle trails compared with on-street cycle lanes, although further work is required to confirm this hypothesis. It is also possible that the types of cyclists using cycle trails and on-street cycle lanes differ. The influence of cyclist and pedestrian characteristics, such as gender and age, on the likelihood of travelling after-dark should therefore also be investigated.

In summary, this work shows the significance of ambient light levels on active travel. Although artificial lighting after-dark is not equivalent to daylight, these results highlight a potential role for road lighting in encouraging active travel, to provide adequate light conditions that minimise the transition in light from daylight to darkness.

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