Speed of Older Cyclists in Difficult Traffic Situations

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Abstract

The bicycle is one of the most widely used means of transport in the Netherlands and contributes to psychological and physical health-related advantages. As the cognitive and health-related decline in older adults increases their crash risk in traffic, research on age-related decline should be conducted to support safe infrastructure for the elderly. For that reason, this study concerned the differences in cycling behaviour between old and young cyclists in so-called 'all-green intersections' in the Netherlands. Participants were only selected if they made a full stop in front of a red traffic light to ensure that they decelerate when approaching the intersections and accelerate when leaving the intersections. Three hypotheses were analysed based on naturalistic video and GPS data: On average (1) older adults cycle slower, (2) brake less hard (decelerate), and (3) speed up (accelerate) less than younger cyclists. For analysis, four variables were designed regarding Mean Speed and Minimum Deceleration when approaching an intersection as well as Mean Speed and Maximum Acceleration when leaving an intersection. For the first hypothesis support was found when the cyclists approached an intersection but not when they left the intersection. Thus, older cyclists approach an intersection slower than younger cyclists but leave with a similar speed. The second and third hypotheses were both not supported by our results, which means that there is no difference in braking behaviour and acceleration behaviour between the two age groups. These findings indicate that the age difference might have been too small for identifying differences between the two age groups. Future research should focus on the differences in age-related decline, influencing the cycling behaviour of cyclists from specific age periods.

Keywords: cycling, old, young, ageing, speed, deceleration, acceleration

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Old Age

The effectiveness of medication improved greatly in the past 100 years which prolonged the life expectancy of humans by advancing general health and ageing (Komp & Aartsen, 2013). Ageing is a multifaceted process depending on social, environmental, psychological, and biological elements and is associated with an increase in (chronic) diseases and general decline in health which incorporates slower recovery from illnesses and accidents (Ankri & Cassou, 2013). Health decline can interfere with activities in daily life, making it more difficult to carry out routines (Ankri & Cassou, 2013). The degree to which older adults can perform in daily life varies greatly based on their severity of age-related decline, their compensation strategies for decline and on their social and financial resources (Eby & Molnor, 2009). In terms of gender, there are more women who are 65 years or older than men and, although men self-perceive themselves as healthier, women have a higher life expectancy (Komp & Aartsen, 2013). Therefore, age-related decline does not determine the perception old people have about their capabilities to carry out daily routines (Ankri & Cassou, 2013; Cosentino & Stern, 2019).

So far, 65 years or older has been the main marker for the term ‘old’ in research because this is the typical age for retirement, although retirement age is increasing (66-67 in 2020) (Komp & Aartsen, 2013; Maunder, 2022). Yet, retirement age is a poor marker as medication nowadays is more efficient which results in longer life expectancies and greater health in old age (Komp & Aartsen, 2013). Thus, Komp and Aartsen (2013) suggest defining specific age groups that can be used for any age-related study. They propose two separate periods for ‘old’, with the first period starting at 50 years old (young-old) and the second period starting at 75 years old (old-old) (Komp & Aartsen, 2013). While the first period is characterized by small health-related decline, the second period is defined by severe decline of physical and mental health (Komp & Aartsen, 2013). The age-related decline also varies within these periods, but the measurement possibilities become more specific.

An important part of age-related decline affecting daily life is cognition which consists of multiple abilities (Martin et al., 2013). Functions related to cognition can be grouped into two entities, fluid intelligence and crystallized intelligence. While studies concerning crystallized intelligence (e.g., vocabulary) even reported increase into old age, fluid intelligence (e.g., verbal fluency, processing speed) is usually characterized by age-related decline. The ageing of cognition is multidimensional, multidirectional, influenced by generation and, therefore, highly individual (Martin et al., 2013). Nevertheless, there is a general decrease in the speed of performing mental operations regarding all aspects of fluid intelligence, affecting especially processing speed and inhibitory control (Boele-Vos et al., 2017; Martin et al., 2013).

Apart from cognition, physical decline has a great impact on old individuals' lives as well. Reductions in bone strength and fracture tolerance or diseases like arthritis, rheumatism, neurological disorders, cardiovascular diseases, pulmonary diseases (decreased ventilation) and musculoskeletal problems are examples of common physical age-related decline (Fildes et al., 2008; Walsh et al., 1999). Musculoskeletal problems can reduce muscle strength and muscle power. Muscle strength is the ability to use one group of muscles to overcome a specific resistance (lifting weight on a bench press) while muscle power is a product of velocity and force induced by muscle contraction which is necessary for cycling (Bellumori et al., 2017). Cognitive and physical decline cannot be stopped but it can be limited by enhancing personal resources (friendships, healthy diet) and engaging in physical activities like cycling (Ankri & Cassou, 2013; Bellumori et al., 2017).

Cycling, Crash Risk and Speed

Cycling does not only contribute to physical activity, but also to cardiovascular health and aerobic fitness which can prevent several diseases (Tranter, 2012). Moreover, through lower extremity exercise (pedaling), upper extremities improve accordingly, which suggests neural adaptations (Bellumori et al., 2017). Thus, cycling can improve neuromuscular function and mobility in older adults which has a positive effect on balance, flexibility, muscle strength, muscle power and endurance (Bellumori et al., 2017). Further, cycling has environmental advantages because it causes no noise or air pollution and does not consume any fossil fuels (Tranter, 2012). In social terms, bicycles are more equitable because they are not as expensive as cars. Hence, nearly everyone is able to afford a bicycle (Tranter, 2012). That reduces the form of hierarchy caused by the economic and social status of cars where expensive brands might represent higher economic and social status (Tranter, 2012). Car drivers might argue that the car is faster than the bicycle but that is not true in its entirety. Taking the raw speed into account, a car is faster but considering indirect costs (air pollution) and direct costs (gas) a bicycle can be faster when cycling through the city, especially in countries with bicycle-oriented infrastructure like the Netherlands or Denmark (Schepers et al., 2013; Tranter, 2012, Jacobsen & Rutter, 2012). In less bicycle-oriented countries like China bicycles are not faster than cars due to the mix of motorized and non-motorized traffic, but the health advantages of cycling remain (Jacobsen & Rutter, 2012).

The difference in infrastructure between countries is a major factor in safe mobility (Jacobsen & Rutter, 2012; Reynolds et al., 2009). Reynolds et al. (2009) reported that purpose-built bike paths and lanes, separated from motor traffic, reduce the risk of crashes. Additionally, a separated infrastructure reduces a perception bias by cyclists about crashes with cars being the number-one crash type (Schepers et al., 2020). The reduced exposure to motor traffic corrects the perception of cyclists to the fact that a single-bicycle crash (e.g., falling off the bicycle, colliding with an obstacle) is the most frequent crash type independent of the volume of traffic (Schepers et al., 2020). Although single-bicycle crashes remain as the most prevalent crash type for cyclists, the general number of crashes are reduced in countries where cyclists are less exposed to motor traffic (Schepers et al., 2013; Schepers et al., 2020). In addition, separated traffic encourages cycling because there is an inverse correlation between the volume and speed of traffic and the number of cyclists, meaning that the more motorized traffic, the less cyclists on the street. That is mainly due to the greater fear of a crash of cyclists in mixed traffic (Jacobsen & Rutter, 2012).

Other factors that influence crash risk for cyclists are being distracted by others, limited width of paths, curves, obstacles, slopes, and road surface issues, overseeing others, losing balance and veering off course unintentionally (Boele-Vos, Duijvenvoorde, 2017; Westerhuis & de Waard, 2016). When considering the distraction by others one should be aware that it is difficult to interpret the behaviours of other cyclists which could explain why individuals report crash risks due to misinterpretation of other road users' intentions (Westerhuis & de Waard, 2017). In the Netherlands, the crash risk for cyclists without a motor vehicle increased by 5.4 percent every year since 1996 but motor vehicles crashes decreased by 4.4 percent every year (Schepers et al., 2017). While motor vehicles crashing into bicycles were more dangerous in the past, they only became slightly more dangerous than crashes without motor vehicles nowadays (Schepers et al., 2017). The greatest risk is posed to old cyclists which is due to the multiple factors (e.g., physical/mental decline) mentioned in the part about 'Old Age' and the fact that the number of older cyclists increased in the past few years (Ankri & Cassou, 2013; Schepers et al., 2017).

The probability of older people to suffer an injury in a cycling accident is three times higher than for younger cyclists, and the risk to fall off a bicycle for cyclists who are 65 years or older has an annual increase of 7.3 percent (Engbers et al., 2018). The physical slowness that older adults experience is linked to postural instability which reduces their ability to keep their balance, flexibility, strength, and endurance on the bicycle (Bellumori et al., 2017). A common strategy of older cyclists to counteract the reductions is to pay attention to their outward knee movement while cycling (Bulsink et al., 2016). That strategy is a solution that might help in general but can be an extra strain in difficult traffic situations due to the higher cognitive workload that older brains already endure (Bulsink et al., 2016, Boele-Vos et al., 2017). In fact, there is an increased physical effort for both young and old cyclists in complex traffic sections (e.g., crossing an intersection, cycling uphill) which resulted in a deteriorated detection of relevant stimuli (Boele-Vos et al., 2017). However, older cyclists had slower reaction times and lower hit rates in stimuli detection than younger cyclists (Boele-Vos et al., 2017). Due to the reduced ability to counteract such high frequency perturbations (e.g., forcing the cyclists to slow down) the older cyclists reduce their speed which can result in higher instability and a single-bicycle crash (Bulsink et al., 2016). Westerhuis et al. (2020) found that shoulder strips for the cyclists and edge strips on bike paths may reduce the risk for single-bicycle crashes. Infrastructural modifications like edge strips can be a population-wide prevention of injuries without action required by cyclists themselves (Reynolds et al., 2009). Thus, older cyclists experience more age-related difficulties in traffic, but solutions like shoulder strips might enhance safety in traffic for everyone.

Speed is a component influencing safe mobility (Aarts & Schagen, 2005). Studies regarding the speed of cyclists are not congruent in their results. In a task where cyclists had to turn left at an intersection, middle adulthood cyclists were on average 2.6 km/h faster than older cyclists, but on an e-bike older cyclists were as fast as younger cyclists on a conventional bicycle (Vlakveld et al., 2014). While Vlakveld et al. (2014) stated that there was no difference in mental workload based on the bicycle type, they found a higher speed-related mental workload in older adults than in younger adults. Boele-Vos et al. (2017)

supports that but also links the speed component to the bicycle type by stating that older cyclists detected less stimuli and had slower reaction times in difficult traffic situations (e.g., crossing a busy intersection) on an e-bike than on a conventional bicycle which was not the case for the younger cyclists. The mental workload could be negatively influenced when older individuals use an e-bike, but Theurel et al. (2012) reported that oxygen uptake and heart rate are lower on an e-bike and the time to perform in a ‘complete mail sorting test’ after an e-bike cycling session was shorter than after a conventional bicycle ride. This could mean that there is a reduction in muscle strains and psychological stress when using an e-bike according to Theurel et al. (2012). Hence, mental workload could be higher for older cyclists when cycling fast in general but using an e-bike could reduce their physical effort and improve their cognitive skills after cycling on an e-bike. The findings remain uncertain and contrary which makes the investigation even more relevant.

In a study regarding the crash rate of older car drivers by Aarts and Schagen (2005), an increase in crashes was reported with increased speed and cars driving on a minor road. In line with data about cycling, it was reported that lane width, junction, density, and traffic flow are factors influencing crash risk of car drivers (Aarts & Schagen, 2005). Research regarding car crashes agreed that crash risk increases when the vehicle is faster than the traffic surrounding it (Aarts & Schagen, 2005; Jacobsen & Rutter, 2012). This was not yet reported for bicycles although Jacobsen and Rutter (2012) claim that the biggest risk factor for death of a cyclist is the speed and mass of a motor vehicle. Hence, the bigger and faster the motor vehicle, the more likely it is to die for a cyclist. This is plausible as a truck driver has less sight around his vehicle than a driver of a passenger car and the faster a motor vehicle drives the harder it hits a cyclist in a crash (Jacobsen & Rutter, 2012). It is therefore crucial to examine whether speed differences between old and young cyclists exist and how that might influence safe mobility.

Current Study Approach

The current study concerns the differences of cycling behaviour between a young-old age group and a young-young age group according to Komp and Aartsen (2013). Although general health has greatly improved in Europe, the age-related decline in older adults has a negative impact in terms of cognitive and physical slowness on daily routines (Ankri & Cassou, 2012; Komp & Aartsen, 2012). Especially for cycling, cognition and physical effort go hand in hand which makes its execution more difficult with increasing age (Bellumori et al, 2016; Boele-Vos et al., 2017). For car crashes it was found that a vehicle moving faster than the traffic around it, the crash risk increases which was not yet confirmed for bicycles (Aarts & Schagen, 2005; Jacobsen & Rutter, 2012). Due to the lack of knowledge and the incongruency of the impact of speed on bicycle crash risk, comparing between age groups, three different hypotheses were established.

Hypothesis 1: On average, older cyclists are slower than younger cyclists in a difficult traffic situation. *Hypothesis 2:* On average, younger cyclists brake harder than older cyclists in a difficult traffic situation. *Hypothesis 3:* On average, younger cyclists accelerate faster than older cyclists when leaving a difficult traffic situation.

Method

Datasets

The data analysed in this study were provided by the university of Groningen. In total there were four datasets containing naturalistic data gathered in 2013, naturalistic data from 2015, experimental data from 2017 and experimental data from 2018. All datasets consisted of video files with cyclists recording either their daily routes (naturalistic) or planned routes (experimental).

Naturalistic data

Naturalistic cycling is considered to be cycling in a daily-life setting. This is advantageous as the participants' regular cycling behaviour is not manipulated by a lab setting situation. Hence, social desirability is less influential and the participants are less likely to engage in different cycling behaviour (e.g., cycling slower than they usually would) compared to a lab setting. The naturalistic datasets were originally collected for Westerhuis and De Waard (2016) in which the participants had to operate the cameras themselves by mounting them on the front of their own bicycles and switch them on/off. Further information about the naturalistic data gathering can be found in Westerhuis and De Waard (2016).

Experimental data

The second part of the data consists of an experimental dataset originally gathered for studies at the University of Groningen in 2017 and 2018. For the experimental dataset the participants did not mount the cameras themselves as bicycles were prepared by the researchers. Another difference compared to the naturalistic method is that the experimental gathering was controlled by instructing the participants to cycle the same predefined route. Thus, they all crossed the same intersections (e.g., Vrydemalaan/Wouter van Doeverenplein/ S. S. Rosensteinlaan; see Figure 3 in Appendix) while for the naturalistic data, only similar intersections could be used for analysis. Additionally, the participants of the experimental data only had a 20 to 30 minutes bike ride while the naturalistic participants used the cameras for one week cycling without predefined routes.

Selection Criteria

The selection criteria were that the cyclists crossed so-called 'all-green intersections' in the city of Groningen. The 'all-green intersections' stood out by separating car traffic lights from bicycle traffic lights. The traffic lights for bicycles had their red and green phases at the same time from all directions. The bike traffic lights had to be red for the participants when approaching an intersection to make them have a full stop. The full-stop-criterion enabled an observation and analysis of the participants' deceleration and acceleration behaviour before and after making a full stop (see Figure 4 in Appendix for an 'all-green intersection').

Participants

The selected participants of the naturalistic dataset were separated into two age groups. The first age group consisted of participants being 50 years or older and the second age group included participants between 20-30 years old. From the naturalistic datasets 20 old participants (*M* age = 65.65, *SD* = 7.35) and five young participants (*M* age = 28.80, *SD* = 6.34) fulfilled the selection criteria. Further 15 participants from the experimental dataset (*M* age = 21.13, *SD* = 0.915) were randomly allocated to the young participants of the naturalistic dataset to create a group of 20 young participants (*M* age = 23.05, *SD* = 4.55) as the naturalistic sample size of the young participants was much lower than the naturalistic sample size of the older participants. Due to the differences in data collection the young participants of the experimental and naturalistic dataset were compared to verify whether their behaviour was comparable, despite of the research setting. As soon as that was analysed, the old and young age groups were compared regarding speed, deceleration, and acceleration.

Materials and Procedure

The participants were all asked to fill out a questionnaire gathering demographic information and more specific information about cycling behaviour. For the current study only the demographic information (age, gender) was of interest. The videos of all datasets were opened in the program 'DataKam' which shows the video, speed, and GPS location of the participants. Subsequently, the video files which showed participants having a full stop at an 'all-green intersection' were included for the statistical analysis. For extracting the GPS information from the video files into 'Csv files' the program 'Contour Storyteller' was used. The 'Csv files' were further processed in 'Microsoft Excel'. For each full stop/'all-green intersection', two time-windows of ten seconds were extracted from the Excel Workbooks and copied into another Excel file. An example of a time window can be found in Figure 5 (Appendix). The first time-window started ten seconds before the full stop (stopping condition) and the second time window started after the traffic lights for bicycles turned green for ten seconds (leaving condition). In Figure 6 the speed and change of speed values for an intersection are listed (see Appendix).

Statistical Analysis

For each participant, mean speed and minimum deceleration were calculated as dependant variables for the stopping condition, and mean speed and maximum acceleration were calculated as dependent variables for the leaving condition. Minimum deceleration (hardest brake) and maximum acceleration (highest speedup) were calculated separately because deceleration entails negative values and acceleration includes positive values. The mean speed was calculated separately for the young participants of the naturalistic and experimental data to see if they can be used as one variable. This was necessary due to the differences in data collection methods.

For the current research a mixed design consisting of a between-subjects-factor (age) and a within-subjects-factor (location) was conducted. In other words, there is a factor comparing between old and young cyclists and a factor considering differences in cycling behaviour over multiple intersections. The program 'SPSS' was used to conduct statistical tests. For the comparison between the young participants of the naturalistic and experimental datasets an independent t-test was conducted. For the between-subjects factor an ANOVA was conducted whilst for the within-subjects factor a Repeated Measures ANOVA was conducted. Since the number of intersections crossed by each participant varied, the within-subjects analysis had to be broken down into two intersections. This was necessary as SPSS is not able to run a repeated measures ANOVA with varying numbers of measurements.

Moreover, six of the 40 participants had to be excluded as they only crossed one intersection which makes a repeated measure impossible. For those participants who crossed more than two intersections, a random selection of two intersections was executed.

Results

The goal of this study was to identify differences between old and young cyclists while approaching or leaving intersections. The Stopping Condition determined that the cyclists approach a red traffic light resulting in a full stop. The Leaving Condition incorporated cyclists leaving the intersection when the traffic lights turned green again. Firstly, the similarity between the naturalistic and experimental studies with young participants was verified because as soon as similarity was the case, both datasets could be used as one dataset. Secondly, the comparison between old and young participants was conducted. Thirdly, since different intersections were passed, a comparison between locations within each participant was executed. The mean speed variables were measured in meters per second (m/s) and the deceleration/acceleration values were measured in meters per second squared (m/s^2).

Comparing Young Participants

An independent samples t-test was conducted which compared the means of Stopping Condition Mean Speed, Stopping Condition Minimum Deceleration (hardest brake), Leaving Condition Mean Speed, and Leaving Condition Maximum Acceleration (highest speed-up). The means and standard deviations of those conditions can be found for each study method in Table 1. For all conditions the t-test turned out non-significant (see Table 2). Thus, between the study methods there is no significant difference in speed (t (18) = -0.05, p = .96) and braking (t (18) = .80, p = .44) when approaching the intersection as well as no difference in speed (t (18) = 0.22, p = .83) and fastest acceleration (t (18) = -0.89, p = .39) when leaving the intersection. Therefore, the two datasets were used as one ‘young’ dataset for further tests.

Table 1

Descriptives of the young participants from experimental and naturalistic studies

Condition	Variable	Study Method	N	Mean	SD	S.E.
Stopping	Mean Speed	Naturalistic	5	2.66	0.71	.32
		Experimental	15	2.68	0.85	.22
Stopping	Minimum Deceleration	Naturalistic	5	-0.82	0.50	.22
		Experimental	15	-1.00	0.42	.11
Leaving	Mean Speed	Naturalistic	5	2.48	0.79	.35
		Experimental	15	2.40	0.62	.16
Leaving	Maximum Acceleration	Naturalistic	5	0.81	0.45	.20
		Experimental	15	0.99	0.38	.10

Table 2

T-test comparing the differences between young participants

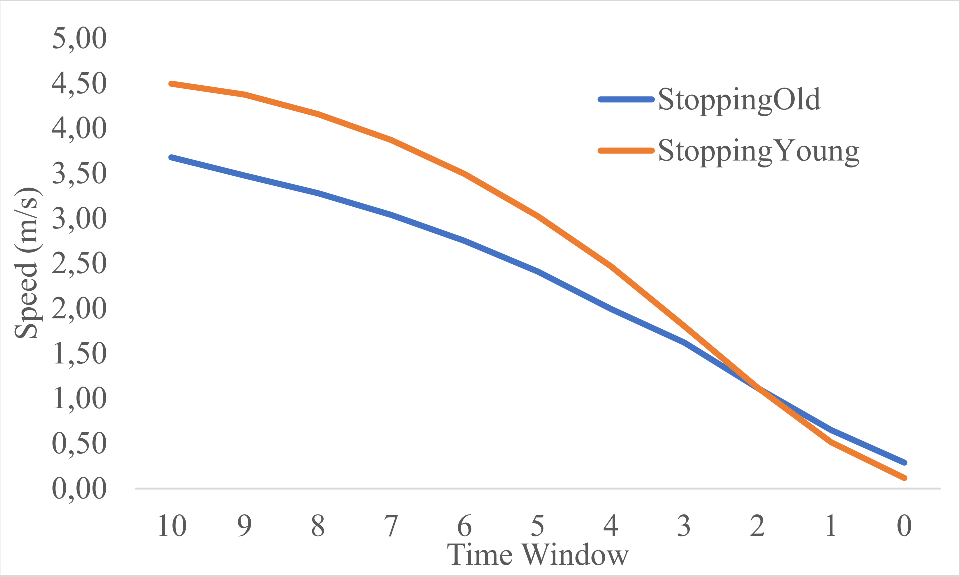
					95% Confidence Interval	
Condition	Variable	t	df	p	Lower	Upper
Stopping	Mean Speed	-0.05	18	.96	-.91	.87
Stopping	Minimum Deceleration	0.80	18	.44	-.29	.65
Leaving	Mean Speed	0.22	18	.83	-.64	.79
Leaving	Maximum Acceleration	-0.89	18	.39	-.62	.25

Comparing Age Groups

In Figure 1, the speed reduction profiles when approaching an intersection are visualized for old and young participants. It is visible that ten seconds before making a full stop, the young participants decelerated from a higher speed than the old participants. While the profile of the old participants seems more linear, the young participants' profile decreases more exponentially. In the second half of the time window the slopes of the profiles resemble each other more than in the first half because the participants come within reach of the full stop. Overall, it seems that the young participants approached the intersections with higher speed, reduced their speed less linearly than the old participants, and braked harder before they fully stopped. This resembles a pattern of 'braking harder' which could indicate that the young participants decreased their speed quicker than the older cyclists.

Figure 1

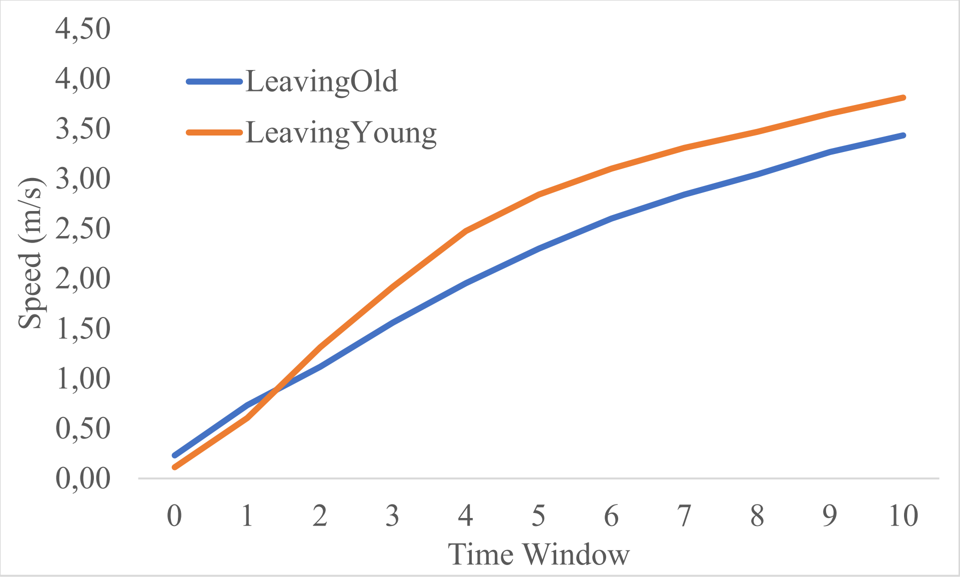
Stopping Condition Mean Speed profiles for the old and young age groups



As opposed to Figure 1, Figure 2 shows the mean speeds of the older and younger cyclists during the Leaving Condition. The young participants accelerated slightly slower in the beginning but between second one and two the profiles cross. From that moment on, the young participants seem to have speeded up faster than the old participants. In contrast to the young participants, it looks like the old participants accelerated more linearly and have a gentler slope value in general. In other words, the young participants accelerated faster, and therefore seem to have reached higher speeds starting from two to three seconds after leaving an intersection. Comparing Figure 1 and 2, it is identifiable that the profiles in Figure 1 seem to be more distant from each other than the profiles in Figure 2. That indicates higher differences in speed between age groups when approaching the intersection than when leaving the intersection.

Figure 2

Leaving Condition Mean Speed profiles for the old and young age groups



For testing the effects of age, the same four variables that were compared in the t-test were used to differentiate between old and young participants (i.e., Mean Speed, Minimum Deceleration, Maximum Acceleration). The mean values suggest small differences between old and young participants, with the young age group showing higher means than the old age group in Stopping Condition Mean Speed (*Mo* = 2.21; *My* = 2.68), Leaving Condition Mean Speed (*Mo* = 2.11; *My* = 2.42) Stopping Condition Minimum Deceleration (*Mo* = -.86; *My* = -.95) and Leaving Condition Maximum Acceleration (*Mo* = .72; *My* = .95). As visible in Table 4, the difference between age groups of Stopping Condition Mean Speed (*F* (1) = 4.40, *p* =

.04) was significant while the difference was insignificant for Stopping Condition Minimum Deceleration (F (1) = 0.65, p = .43). This suggests that when approaching an intersection, young and old participants differ in speed but not in maximum braking.

The Levene's test for homogeneity revealed that the Leaving Condition's homogeneity of variances was violated. The Mann-Whitney U Test was applied because it is robust to homogeneity violation. For the Leaving Condition Mean Speed, the effect was insignificant (*MWU* = 255, p = .14) and the Leaving Condition Maximum Acceleration had an insignificant (*MWU* = 266, p = .08) result as well (see Table 5). This implies that young and old participants do not differ significantly in maximum speed up when leaving the intersection. Nevertheless, a medium effect size ($\eta^2 = 0.11$) suggests that there could be practical significance for Leaving Condition Maximum Acceleration. A medium effect size for a difference in acceleration when leaving an intersection could mean that either the significance test result is inaccurate, meaning there is an effect, but the used sample size or type of analysis could not reveal it, or the effect size is inaccurate which means there is no effect at all. Therefore, the result remains uncertain, and no definite conclusion can be drawn based on the test results of Leaving Condition Maximum Acceleration.

Table 3

Descriptive Statistics of the young and old age groups

Condition	Variable	Group	Mean	SD	N
Stopping	Mean Speed	Old	2.21	0.60	20
		Young	2.68	0.80	20
Stopping	Minimum Deceleration	Old	-0.86	0.31	20
		Young	-0.95	0.43	20
Leaving	Mean Speed	Old	2.11	0.39	20
		Young	2.42	0.64	20
Leaving	Maximum Acceleration	Old	0.72	0.21	20
		Young	0.95	0.40	20

Table 4

ANOVA of the comparison between age group

Condition	Variable	df	Mean Square	F	p	η^2
Stopping	Mean speed	1	2.18	4.40	.04	.10
Stopping	Minimum Deceleration	1	0.09	0.65	.43	.02

Table 5

Non-parametric test of the effects of age groups

Condition	Variable	MWU	p	N
Stopping	Mean Speed	299.5	.01	40
Stopping	Minimum Deceleration	172.5	.46	40
Leaving	Mean Speed	255	.14	40
Leaving	Maximum Acceleration	266	.08	40

Effects of Location

The descriptive statistics of the within-subjects analysis show that the means of Location 1 for Stopping Mean Speed (*M1* = 2.56, *M2* = 2.46, *SD1* = .10, *SD2* = .84), Stopping Minimum Deceleration (*M1* = -1.06, *M2* = -.92, *SD1* = .44, *SD2* = .39), and Leaving Maximum Acceleration (*M1* = .97, *M2* = .91, *SD1* = .42, *SD2* = .35) are all higher than the means for Location 2. Only Leaving Mean Speed (*M1* = 2.37, *M2* = 2.25, *SD1* = .64, *SD2* = .70) shows a higher mean value for Location 2. The differences in means are identifiable but the discrepancies are small.

For the within-subjects analysis a repeated measures ANOVA was conducted. The effects between locations for Stopping Mean Speed turned out to be insignificant (*F* (1) = 0.49, *p* = .49), as well as for Leaving Mean Speed (*F* (1) = 1.0, *p* = .32) and Leaving Acceleration Maximum (*F* (1) = 0.98, *p* = .33) (see Table 3). However, the differences between locations for Stopping Deceleration Minimum was significant (*F* = 4.13, *p* = .05) (see Table 3). This indicates that different locations influenced the hardest brake reaction when approaching an intersection, but the locations did not influence the mean speed when approaching an intersection, the mean speed when leaving an intersection, and how fast the participants accelerate when leaving the intersection.

Table 6

Descriptive Statistics of the within-subjects analysis

Location	Condition	Variable	Mean	SD	N
1	Stopping	Mean Speed	2.56	0.10	34
2	Stopping	Mean Speed	2.46	0.84	34
1	Stopping	Minimum Deceleration	-1.06	0.44	34
2	Stopping	Minimum Deceleration	-0.92	0.39	34
1	Leaving	Mean Speed	2.37	0.64	34
2	Leaving	Mean Speed	2.25	0.70	34
1	Leaving	Maximum Acceleration	0.97	0.42	34
2	Leaving	Maximum Acceleration	0.91	0.35	34

Table 7

Within-subjects analysis regarding different locations

Source	Condition	Measure	df	Mean Square	F	p	η^2
Location	Stopping	Mean Speed	1	0.15	0.49	.49	.02
	Stopping	Minimum Deceleration	1	0.31	4.13	.05	.11
	Leaving	Mean Speed	1	0.23	1.00	.32	.029
	Leaving	Maximum Acceleration	1	0.07	0.98	.33	.029

Discussion

The present study had three major purposes. First of all, it was investigated whether older cyclists are on average slower than younger cyclists before and after stopping for a red traffic light. Secondly, it was examined whether older cyclists brake less hard when approaching an intersection than younger cyclists. Thirdly, it was investigated whether older cyclists accelerate, on average, slower than younger cyclists when leaving an intersection. Secondary purposes were for the accuracy of the analysis to scrutinize if there is a difference between outcomes of the experimental and naturalistic datasets and whether cycling behaviour is consistent over multiple intersections. Contradictory results were found regarding overall speed, reporting older cyclists to be significantly slower when approaching the intersection but not when leaving the intersection. In opposition to the expectations, no support was detected for older cyclists braking less hard when approaching an intersection, nor for older cyclists accelerating slower than younger cyclists when leaving an intersection. In other words, old participants were on average slower when approaching an intersection but not when leaving the intersection. Young participants do not brake harder when approaching an intersection and older cyclists do not accelerate slower than younger cyclists when leaving an intersection. Nevertheless, no difference was identified between the experimental and naturalistic datasets. Furthermore, passing different intersections only had an influence on how hard the participants brake when approaching an intersection.

Theoretical Implications

Based on research suggesting that older cyclists are on average 2.6 km/h (0.72 m/s) slower than younger cyclists on commercial bicycles and past findings on the age-related decline of processing speed in performing mental operations (Vlakveld et al., 2014; Ankri & Cassou, 2013; Martin et al. 2013), it was hypothesized that older cyclists are on average slower than younger cyclists when approaching an 'all-green intersection' and when leaving an 'all-green intersection'. When the participants approached the measured intersections, this hypothesis was supported by the findings of this study, although the mean speed difference in the current study was only 0.47 m/s when approaching an intersection which is logical because the participants had to make a full stop. In Vlakveld et al. (2014) the participants had to cross an intersection without a full stop which means they did not decelerate a much as in the current study. Nevertheless, it indicates that older cyclists are on average slower than younger cyclists in the time frame before fully stopping for a red traffic light. However, when the participants left an intersection no significant difference in speed was found between the two age groups. This suggests that in the ten seconds when leaving an intersection there is no difference in speed between young and old cyclists.

A possible explanation for this incongruency is the difference between the conditions. In Figure 1 and Figure 2 of the Results section, it was observable that the younger cyclists reduced their speed later than the older cyclists when stopping for the red traffic light. In the time frame when leaving the intersection, the two age groups accelerated on average more similarly. Boele-Vos et al. (2017) argued that less stimuli were detected in difficult traffic situations by both age groups. Stopping for a red traffic light is less complex than leaving an intersection as there are less stimuli (i.e., other cyclists) to process. This could implicate that the higher the workload, when leaving an intersection, the more similar the two age groups act. Vice versa, when approaching the intersection, the differences become more visible because the age groups are less distracted by many stimuli but the age-related decline in older cyclists still limits them.

Likewise, reduced bone and muscle strength, flexibility, range of motion, and vision-related deficits in older age was indicated (Eby & Molnar, 2009; Fildes & Carlton, 2008). Moreover, Bellumori et al. (2017) reported reduced muscle strength and muscle power in ageing which led to the hypothesis that older cyclists brake less hard and accelerate less quickly than younger cyclists. It was assumed that young cyclists can bring up more muscle power and, thus, stop later than older cyclists who would decelerate more gently due to reduced muscle power. Although the means indicated a slight difference in braking behaviour, the hypothesis could not be significantly supported. As a result, younger cyclists do not significantly brake harder than older cyclists within ten seconds before stopping for a red traffic light. The speed one chooses when leaving an intersection can be influenced by many factors, including the general choice of speed but also the enhanced stimuli in ‘all-green intersections’. The more traffic from different directions, the more one is forced to reduce its speed independent of the age. Further, the cyclists could have been influenced by other cyclists in front of them when the traffic light turned red. If slower cyclists were in front of faster cyclists, the faster cyclists were automatically forced to decelerate slower as well.

The contrast to our expected outcome could be explained by the difference of age-related decline being too small between the age groups. Komp and Aartsen (2013) claimed that the difference in age-related decline between a 20-year-old and a 75-year-old is greater than between a 20-year-old and a 50-year-old. A 50-year-old usually experiences small health-related decline while a 75-year-old is more likely to experience severe health-related decline (Komp & Aartsen, 2013). Hence, the difference of muscle power between our chosen age groups may have been too small.

A statistical explanation for the incongruency could be the used statistical method consisting of mean values and not of time-specific deceleration and acceleration scores. The values used for the ANOVA were the acceleration and deceleration means of the young and old age group averaged over all ten seconds of the time windows, potentially omitting differences in braking and speeding up behaviour on any specific moment within that time-window. Averaging the values could have limited the significance of the analyses. Thus, the analyses used in the current study limit the interpretation of the outcome to a general conclusion about the entire time-window and do not allow formulating conclusions about time-specific moments. Consequently, there might be time-specific effects which this study did not reveal.

Prior research proposed that older individuals show a decline in inhibitory control, meaning that they are less able to suppress irrelevant stimuli, making them less able to focus on relevant stimuli (Martin, et al., 2013). As the ‘all-green intersections’ cause a lot of stimuli to be present (many cyclists) at the same time, it was hypothesized that older cyclists accelerate slower than younger cyclists when leaving an intersection. In contrast to mean speed when leaving an intersection, the maximum acceleration compared the highest value of speeding up between the two age groups. Again, no support for a significant difference was detected. On the one hand, the old age group might have been as capable as the young age group of processing the various stimuli when leaving the intersection. On the other hand, the time-window could have been too short to identify the acceleration differences between the age groups as young cyclists could have been held back by old cyclists in front of them.

The similarity in acceleration could support the findings by Boele-Vos et al. (2017) stating that the workload becomes higher for both age groups in difficult traffic situations, but it stays in contrast with the assumption of the current study that overall, the mental workload is higher for older cyclists (Vlakveld et al., 2014; Boele-Vos et al., 2017). Eby and Molnar (2009) claimed that functional decline depends amongst others on decline compensation. The compensation in adults being 50 years or older is probably easier to establish than for individuals who are 75 years or older because of less progressed age-related decline in adults younger than 75 (Komp & Aartsen, 2013; Eby & Molnar, 2009).

As the naturalistic method incorporated cyclists passing similar but not the same intersections, it was tested whether there is a difference in cycling behaviour over multiple intersections. The analysis has only shown a significant difference between intersections regarding the hardest brake in the ten seconds before fully stopping for a red traffic light. The intersections can differ in their visibility and volume. If an intersection has less visibility than other intersections, cyclists might reduce their speed earlier and less rapidly for caution.

Further, if one intersection is more busy than other intersections there is a higher probability of other cyclists forcing the participants to brake earlier or differently than they usually would. Lastly, an explanation for different braking behaviour depending on location could be that a traffic light turns red rapidly before a cyclist wanted to pass forcing the cyclist to brake more rapidly. Such factors could have had an influence on the braking behaviour, considering the influence of differing intersections.

Practical Implications

Although the hypotheses were not or only partly supported, the results of this study bear practicability. The minor differences between the age groups did not show significant test results but gave general insight into differences in cycling behaviour between 50+-year-old adults and 20 to 40-year-old adults. Knowing that the differences in speed, braking, and acceleration behaviour was minor between the chosen age groups asks for comparison with an even older age group (75+-years-old). Since there were no participants who were 75 years or older in the current sample, similar studies as this one could be conducted, not only comparing between young and old participants but also comparing between young-old and old-old cyclists. The various comparisons could give insight into changes of decline over specific age periods. Moreover, it could be considered that an ‘all-green intersection’ is not suitable for comparing between age groups because the old age group did not show a higher rate of interruptions or tumbles compared to the young age group. However, comparing at an ‘all-green intersection’ could be suitable for the moment the cyclists had to approach the intersection. Hence, it could be useful for future purposes to study age group differences, comparing the speed when approaching an intersection between specific age groups.

Strengths and Limitations

General Strengths and Limitations

It is important to mention that the four datasets that have been used in this study were gathered in different years. There are data from 2013, 2015, 2017 and 2018. Thus, the infrastructure could be different in each dataset due to reconstruction throughout the years, though no extensive change was observed during data analysis. Despite the minor confounding impact, it could make a difference as this study has shown that location is a crucial circumstantial factor for the intensity of one hitting the brake when approaching an intersection. The entire datasets were gathered in the city of Groningen in the Netherlands. The Netherlands is known for their bicycle-oriented infrastructure which makes this study difficult to generalize to other countries that focus less on bicycle-oriented infrastructure.

Likewise, this study is hard to generalize due to the sample being relatively small compared to, for instance, a naturalistic study with 210 car drivers like Winkelbauer et al. (2019). This was especially the case for the experimental dataset compared to the naturalistic dataset with only five young participants present in the naturalistic dataset. However, compared to other similar studies the sample size in its entirety is average. Further, naturalistic studies like the current or Winkelbauer et al. (2019) have the advantage of using technical devices with GPS systems which is more realistic than a simulator in a lab setting.

An age-related limitation comes up considering that there is no global definition of the terms ‘old’ or ‘young’. While the young participants of the naturalistic dataset were between 25 to 40 years old, the experimental dataset also consisted of participants younger than 25 which is statistically advantageous, but studies are still lacking specific age group definitions. Moreover, the old participants were 50 years or older, but some literature was used for the basis of our hypotheses in which the old age range started from 65 years old on while the old participants of the current study had a mean age of 65. This variety of definitions of ‘old’ and ‘young’ can have an impact on the outcomes of a study as there are differences in age-related decline between a 50-year-old and a 65-year-old. Some research used the term ‘old’ describing individuals being 65 years or older (Schepers et al., 2017) while other studies focused on individuals being 50 years or older (Westerhuis et al., 2020). There would rather be differences between young participants and ‘old-old’ (75+) participants than between young and ‘young-old’ (50+) participants. Therefore, the higher the age-related decline, the higher the chance for finding differences. The fact that the test results were mainly non-significant could be ascribed to a relatively small age-related decline in the young-old age group. If the comparison would have been between an old-old (75+) age group and a young age group, the differences could have been more visible and significant. However, knowing that the differences are relatively small between the young and young-old age group contributes to a basis of knowledge about age differences in cycling behaviour. Several other researchers studied the impact of e-bikes as well which has an influence on speed for both old and young people. In this study only participants on a non-electronic bike were compared.

Comparing experimental and naturalistic study method

A strength of this research was that the naturalistic as well as the experimental datasets were not gathered in a lab setting, establishing a more realistic surrounding for the participants compared to artificial experiments. Further, there was no significant difference found between the experimental and naturalistic datasets, making them suitable to be utilized as one dataset. The participants of the experimental dataset were randomly selected until there were as many young participants as old participants which ruled out a selection bias.

Nevertheless, there are methodological differences that might have influenced the outcome of this study. The t-test comparing the experimental and naturalistic datasets was non-significant, but the sample size was small resulting in reduced accuracy. A naturalistic method is more realistic than an experimental method because the participants are not physically followed by the researcher in a naturalistic setting even though they know that their data will be used for research purposes. Hence, the participants feel less observed and might feel less pressure due to social desirability (Valero-Mora et al., 2013). Westerhuis et al. (2016) reported that in a naturalistic setting the probability is higher to become less aware of the camera as the participants use the camera for a longer period of time. This was not the case for the experimental method in which the cameras were only used for half an hour.

Giving the camera to the participants for a longer period means analysing more video data than in the experimental studies which makes the analysis of naturalistic data more time consuming. Additionally, in the experimental design more control is possible as the researchers mount the camera on the bikes and the route is fixed. Thus, all participants cross the same intersections which reduces the possible confounding effect of location on the results.

Future Research

For future research a consensus should be reached regarding the definitions of ‘old’ and ‘young’ when it comes to studies about age-effects. In such consensus, data from different studies can be correlated more easily. For instance, one may follow the definitions of ‘old’ from Komp and Aartsen et al. (2013), stating that people 50 years or older are ‘young-old’ and people 75 years or older are ‘old-old’ with different progress of age-related decline. Age-related decline is individual but with being more distinct in terms of age groups, study results become more accurate and compliant. That enables comparisons between more specific age groups instead of comparing various classifications of ‘old and young’. On such a basis, it would be expected that the youngest age group differs the most from the oldest age group when focusing on age-related decline. Nevertheless, that also involves a recruitment of more participants. Thus, to compare age effects more reliably, more participants of a higher age should be included.

Future studies should also include e-bikes in regard to speed and age. Due to the fact that most data about e-bikes was from participants who did not cycle in Groningen, it was not possible to include those in this study but, as mentioned before, e-bikes do have an impact on speed in traffic (Vlakveld et al., 2014). So far researchers did not reach consensus regarding the impact of e-bikes in traffic. Scientists agree that cyclists are generally faster on an e-bike, but no agreement was reached when it comes to the effects on mental workload. While Vlakveld et al. (2014) argues that the higher speed on an e-bike raises the crash-rate due to higher workload for the brain, Theurel et al. (2012) claims that physical and psychological performance is improved by the usage of an e-bike. It should be further elaborated how much the higher speed of e-bikes influences difficult traffic situations and if it raises crash rates. In addition, it should also be taken into account how a potential higher speed influences the processing speed of older cyclists because cycling faster probably challenges the brain to process the surrounding faster. Hence, it is of interest to see how older cyclists cope with the higher workload (Vlakveld et al., 2014; Martin et al., 2013; Boele-Vos et al., 2017).

Conclusion

This study investigated the influence of age on cycling speed in ‘all-green intersections’ before and after stopping for a red traffic light, comparing between old and young cyclists. The results indicated that there was support for older cyclists being slower than younger cyclists when approaching the intersection, but not when leaving the intersection. Furthermore, the findings of this study did not reveal differences in how hard someone brakes and how fast one accelerates between the two age groups. Additionally, which intersection was crossed had an impact on how hard someone brakes while approaching a red traffic light. These findings suggest that the age marker for the older age group of this study might have been too low because the decline differences were not statistically identifiable or there are no age-related significant differences. Nevertheless, these findings contribute to the knowledge about differences between age groups in difficult traffic situations.

Notwithstanding some shortcomings, this study adds to prior literature through unique research incentives, especially, as it is the first study examining age-related speed differences of cyclists based on mean speed, minimum deceleration, and maximum acceleration. Lastly, age-related decline will always be an important factor in traffic and should be studied in all its facets in future research. Thus, a greater understanding of age-related decline will contribute to new safety options for elderly individuals and, thus, for the entire traffic.

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Appendix

The Appendix helps to visualize the procedure that was explained in the Method section by showing how different programs were used.

Figure 3

Example of an intersection fulfilling the selection criteria in 'DataKam' (Open Street Map, 2022)

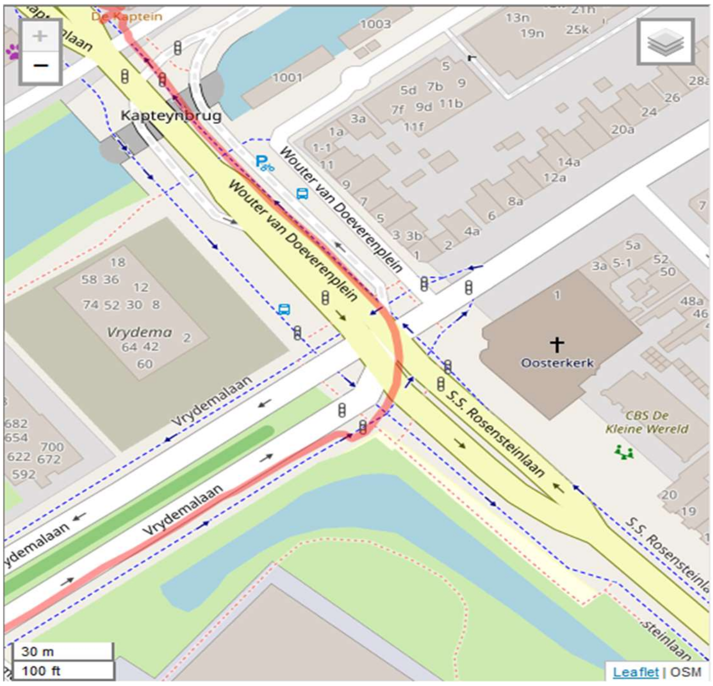
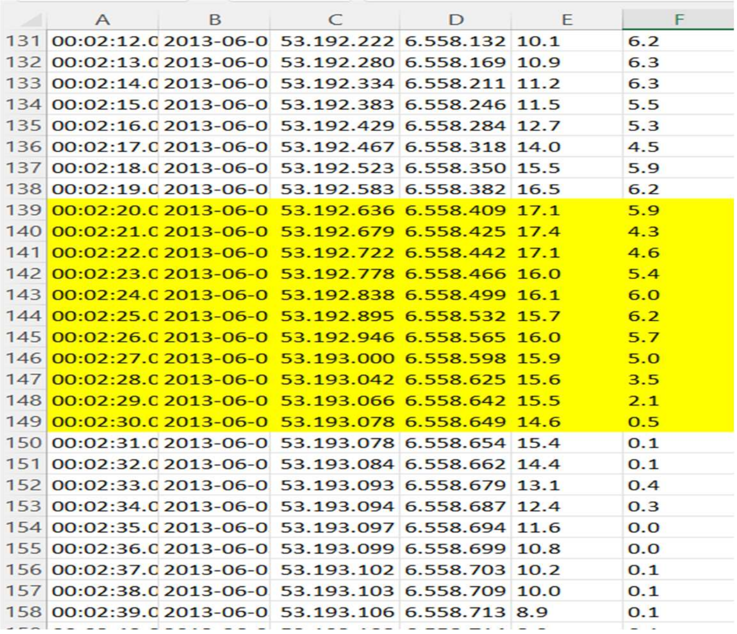


Figure 4

Example of an 'all-green intersection' (Google Earth, 2022).

Figure 5

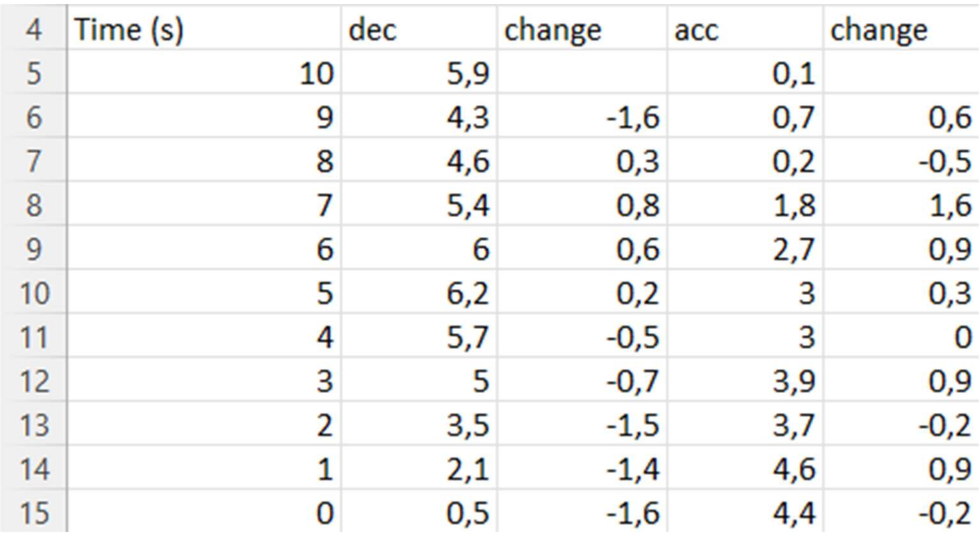
Example of time window in Excel



	A	B	C	D	E	F
131	00:02:12.0	2013-06-0	53.192.222	6.558.132	10.1	6.2
132	00:02:13.0	2013-06-0	53.192.280	6.558.169	10.9	6.3
133	00:02:14.0	2013-06-0	53.192.334	6.558.211	11.2	6.3
134	00:02:15.0	2013-06-0	53.192.383	6.558.246	11.5	5.5
135	00:02:16.0	2013-06-0	53.192.429	6.558.284	12.7	5.3
136	00:02:17.0	2013-06-0	53.192.467	6.558.318	14.0	4.5
137	00:02:18.0	2013-06-0	53.192.523	6.558.350	15.5	5.9
138	00:02:19.0	2013-06-0	53.192.583	6.558.382	16.5	6.2
139	00:02:20.0	2013-06-0	53.192.636	6.558.409	17.1	5.9
140	00:02:21.0	2013-06-0	53.192.679	6.558.425	17.4	4.3
141	00:02:22.0	2013-06-0	53.192.722	6.558.442	17.1	4.6
142	00:02:23.0	2013-06-0	53.192.778	6.558.466	16.0	5.4
143	00:02:24.0	2013-06-0	53.192.838	6.558.499	16.1	6.0
144	00:02:25.0	2013-06-0	53.192.895	6.558.532	15.7	6.2
145	00:02:26.0	2013-06-0	53.192.946	6.558.565	16.0	5.7
146	00:02:27.0	2013-06-0	53.193.000	6.558.598	15.9	5.0
147	00:02:28.0	2013-06-0	53.193.042	6.558.625	15.6	3.5
148	00:02:29.0	2013-06-0	53.193.066	6.558.642	15.5	2.1
149	00:02:30.0	2013-06-0	53.193.078	6.558.649	14.6	0.5
150	00:02:31.0	2013-06-0	53.193.078	6.558.654	15.4	0.1
151	00:02:32.0	2013-06-0	53.193.084	6.558.662	14.4	0.1
152	00:02:33.0	2013-06-0	53.193.093	6.558.679	13.1	0.4
153	00:02:34.0	2013-06-0	53.193.094	6.558.687	12.4	0.3
154	00:02:35.0	2013-06-0	53.193.097	6.558.694	11.6	0.0
155	00:02:36.0	2013-06-0	53.193.099	6.558.699	10.8	0.0
156	00:02:37.0	2013-06-0	53.193.102	6.558.703	10.2	0.1
157	00:02:38.0	2013-06-0	53.193.103	6.558.709	10.0	0.1
158	00:02:39.0	2013-06-0	53.193.106	6.558.713	8.9	0.1

Figure 6

Example of speed and change of speed for one intersection in Excel



4	Time (s)	dec	change	acc	change
5	10	5,9		0,1	
6	9	4,3	-1,6	0,7	0,6
7	8	4,6	0,3	0,2	-0,5
8	7	5,4	0,8	1,8	1,6
9	6	6	0,6	2,7	0,9
10	5	6,2	0,2	3	0,3
11	4	5,7	-0,5	3	0
12	3	5	-0,7	3,9	0,9
13	2	3,5	-1,5	3,7	-0,2
14	1	2,1	-1,4	4,6	0,9
15	0	0,5	-1,6	4,4	-0,2