Title:

Turning the head while biking makes older people lose cycling direction and balance

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Abstract

Background: Bike safety in older subjects is a major concern in multiple countries given the strong increase in the number of cyclists that are admitted to the hospital due to single-sided bicycle accidents in older populations. The increase in single-sided accident rate in older subjects suggests that older adults have more difficulty controlling balance while bicycling in traffic, which has been related to various age-related changes in the sensorimotor system. Yet, the impact of these age-related sensorimotor deficits on the ability of older people to remain stable on their bike during traffic situations such as turning their upper body to check on potential road users, remains unknown.

Methods: We instructed a group of 40 young (22.86 ± 1.53 years) and 41 older participants (62.73 ± 1.57 years) to bike in a straight line while performing a shoulder check movement in order to identify the color of an object presented behind them. We recorded the task-errors (lost balance, errors in identifying the color, cycling outside the lane) and computed the steering angle and rotation of the frame, pelvis and torso from IMU recordings.

Results: We observed that older adults made task-errors (one third of the older participants failed at the task by making errors such as cone-identification errors, loss of balance and cycling outside the lane). In the successful trials, we observed an increase in steering angle and rotation of the pelvis with respect to the frame in the older subjects compared to the young subjects.

Significance: Older cyclists lose balance while turning their head, which might contribute to the increased number of single sided bike accidents in older subjects. The use of simple devices, such as using a mirror, should be encouraged in older subjects to replace the shoulder check maneuver.

1. Introduction

Bicycling is a common mode of transport and is also a popular recreational activity in multiple countries (e.g. Belgium, the Netherland, Denmark). In Flanders (Belgium), 83% of the adult population uses a bicycle (VAB fietsbarometer 2018) and one out of three uses their bicycle daily (Fietsersbond & GRACQ 2019). Similar trends are observed throughout the world. For instance, in Denmark or Norway, bicycle use has increased by 10% over the last 20 years [1,2]. Similarly, the number of cyclists has increased in many European countries since 1990 [3]. Despite the health benefits related to this physical activity [4–6], bike safety is a major concern in these countries. In 2019, 10379 cyclists were injured in an accident, which is the highest number ever reported in Flanders.

Causes of traffic accidents during cycling are related to the interaction between (1) the human on the bicycle, (2) the mechanics of the bicycle, and (3) the environment (including other road users) [7–9]. Accident statistics suggest that these interactions differ in different subpopulations. In young or inexperienced cyclists, most cycling accidents occur in interaction with motorized vehicles, whereas in older adults, there is a strong increase in the number of cyclists that are admitted to the hospital due to single-sided bicycle accidents (i.e., accidents involving the cyclist only) [10]. Between 60% and 95% of cyclists admitted to hospitals are the result of single-sided bicycle accidents [11]. There is a 37% increase in single-sided accidents in older adults compared to the average of all cyclists and a 24% increase in collisions with another obstacle than a road user [12].

The increase in single-sided accident rate in older subjects suggests that older adults have more difficulty controlling cycling direction and balance while bicycling in traffic. Bulsink et al suggested that older adults need more effort to restore from perturbations based on the observation that older subjects use additional strategies, such as outward knee movement, to control balance in response to a perturbation [13]. Neuro-physiological changes in the human body with aging [14], such as frailty, slower reaction times [15], less accurate sensory abilities [16,17], reduced range of motion in the musculoskeletal system [18] and higher mental workload experienced [19,20], might be associated with the observed differences in balance control strategies [13] and the increased number of single sided accidents. For example, the increase of accident risk in older cyclists (on an e-bike) has been related to a relatively higher mental workload for older cyclists (65+ years) compared to a group of younger cyclists (30-45 years) [20]. Yet, the impact of these age-related sensorimotor deficits on the ability of older people to remain stable on their bike during traffic situations such as turning their upper body to check on potential road users, remains unknown.

To fill this gap, we instructed a group of young and a group of older participants to bike in a straight line while performing a shoulder check movement in order to identify the color of an object presented behind them. This task involves both the rotation of trunk and head for perception of the environment and the concurrent control of balance and cycling direction. Therefore, it allows us to investigate the ability of older adults to perform these two concurrent motor tasks. This task is ecologically valid as it is relevant for multiple traffic situations: such as identifying cars behind the cyclist when changing lane or overtaking another road user. We evaluated if the young and older adults could perform the task without errors (e.g. wrong identification, cyclist outside the test track, loss of balance) and if they performed steering corrections to maintain cycling direction.

2. Methods

2. 1 participants

A group of 40 young (22.86 ± 1.53 years) and 41 older subjects (62.73 ± 1.57 years, minimum 60 years and maximum 65 years) subjects participated in this study. Participants were recruited through mailings to local organizations and sport clubs for seniors, through local advertisements and by contacting the social network of the research team. Only participants who cycled at least once a month were included. The study was approved by the local ethics committee (SMEC G-2020-2410) and all participants provided their written informed consent.

2.2 Experimental procedure

We instructed participants to cycle on a self-designed test track that mimicked several real-world conditions on an aluminum bike with (e-bike) or without a motor (conventional bike) (order of the bike was randomized across participants, mass conventional bike = 19.8 kg, details in appendix). Participants biked on the track under three different conditions: first at self-selected speed, then twice more slowly than the self-selected speed and finally while performing a concurrent dual-task. For this paper, we focus on the self-selected speed condition on the conventional bike but the results are identical for the e-bike and for the slow condition (Appendix 2). The subjects familiarized themselves with the cycling track for five minutes (two repetitions) with both the e-bike and the normal bike and subsequently performed one trial that was recorded and analyzed. In the present study we analyzed the part in the test track where subjects had to identify a yellow or red cone behind the cyclist by first looking over the left and secondly over the right shoulder (Figure 1). During the test, the experimenter wrote down (a) whether the participants lost balance and needed to place a foot on the ground or not, (b) whether the participants made mistakes in identifying the cone, (c) and whether they cycled outside the narrow lane with yellow cones (Figure 1).

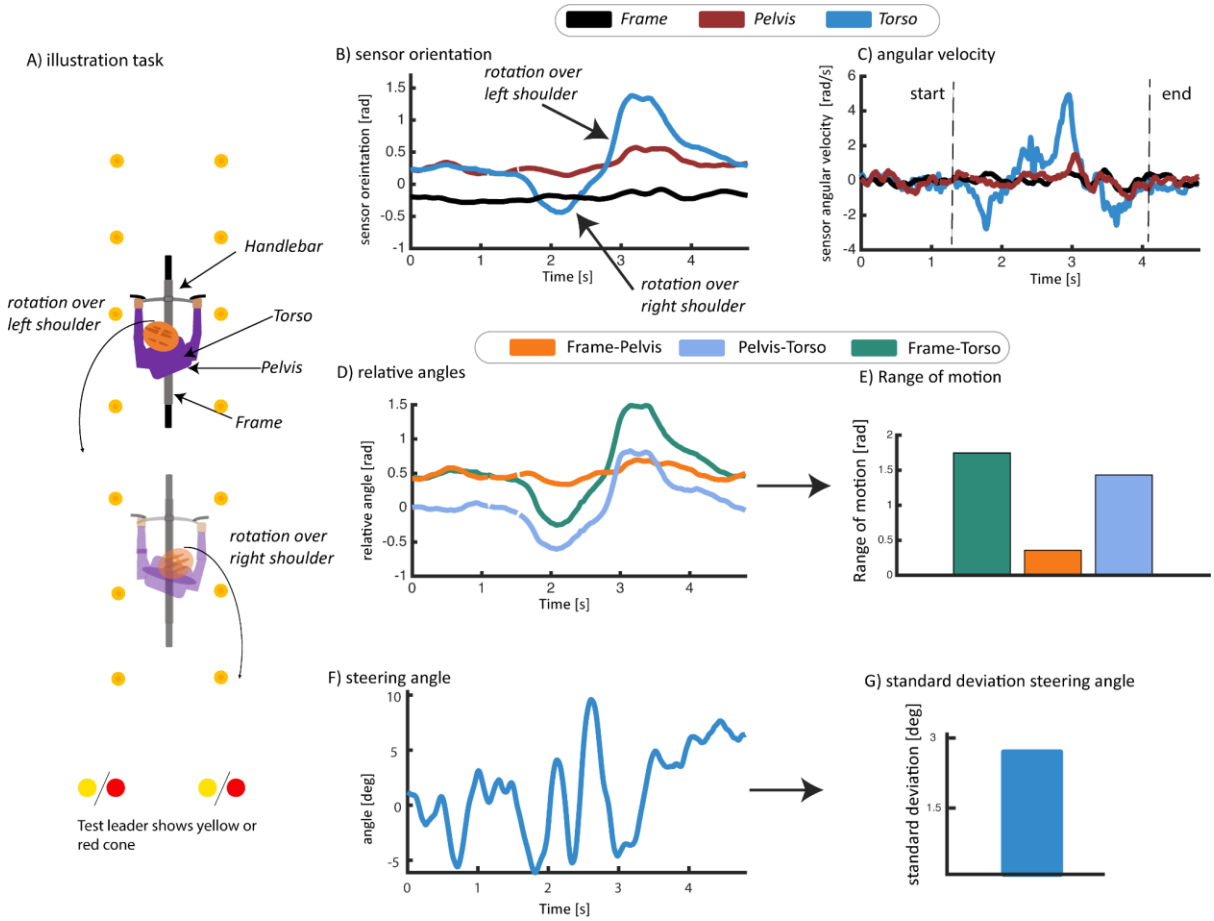

Figure 1: Overview of the kinematic analysis. Young and older subjects identified a yellow or red cone behind the cyclist by first looking over the left and secondly over the right shoulder while cycling in a narrow track between cones (A). The kinematics of the bike and cyclist were analyzed using IMU's on the handlebar, frame, pelvis, torso. Sensor orientations were computed from the IMU raw data and orientations were evaluated around the vertical axis (B). The start and end of the rotation over the right and left shoulder was identified manually based on the angular velocity of sensors (C). Relative changes in orientation between the sensor on the frame, pelvis and torso were computed in the identified time-window to quantify the relative rotation of the segments (D). The range of motion was computed from the relative rotation between the sensors (E). The steering angle was computed as the orientation of the handlebars with respect to the frame along the axis of the stem (F), and the resulting standard deviation in steering angle was compared between the young and older subjects (G).

2.3 Kinematic analysis + determine steering angle

The kinematics of the cyclist and bike was analyzed using inertial measurement units (IMU) mounted on the handlebars, frame, pelvis and torso (MTw Awinda, Xsens, The Netherlands). Sensor orientations were computed from the raw IMU data using the Xsens sensor fusion algorithm in proprietary software MT manager (Xsens, The Netherlands). Sensor orientations were exported as rotation matrices for further analysis.

The steering angle is defined as the rotation of the handlebars with respect to the frame along the hinge of the stem. First, we estimated the axis of the stem by solving a least-squares problem based on a calibration movement where the subject rotated the handlebars through the full range of motion when the bike was in a static position [21]. This method relies on the assumption that the change in orientation between the steer and the frame mainly occurs around one axis (i.e., the axis of the stem) during the calibration movement. Second, we used

euler angles to compute the steering angle as the orientation of the stem with respect to the handlebars along the axis of the stem for all recorded frames.

The orientation of the sensors and the relative angles between sensors were analyzed along the vertical (gravity) axis by converting the rotation matrices to euler angles. The range of motion, defined as the maximal angle between sensors, was computed for the rotation of the pelvis with respect to the frame, the torso with respect to the frame and the torso with respect to the pelvis (Figure 1). The start and end of the rotation over the right and left shoulder was identified manually based on the angular velocity of the torso sensor along the vertical axis (Figure 1c).

2.4 Excluded data

To explore if young and older subjects used different kinematic strategies during this task we evaluated the range of motion between the IMU sensors on frame, pelvis and torso for the subjects that performed the trial successfully. The data of subjects that lost balance (i.e. foot on the ground, cycling outside the lane) or made mistakes in identifying the cones was excluded from the kinematic analysis. We additionally had to exclude data for several young and older subjects due to a faulty wireless connection between the IMU sensors and the base station. There was mainly a data loss for the sensor on the pelvis (17 young subjects, 9 older subjects) and to a lesser extent for sensors on frame, torso and handlebars (4 young and 4 older subjects). We therefore have a different number of participants depending if the outcome measure included the pelvis sensor or not (See Figure 2B and 3). Note that the errors in the task-performance were reported for all subjects (Figure 2A).

2.5 Outcomes and statistics

The assumption of a normal distribution was tested using a Shapiro-wilk test for the data of the young and older subjects. Depending if the assumption of normal distribution was violated, we used a two-tailed Mann-Whitney U test or an independent t-test (ttest2, Matlab 2019) with an alpha of 0.05 to compare the relative range of motion of the sensors on the frame, pelvis and torso and the standard deviation in steering angle between the young and older subjects.

3. Results

Older adults had more difficulties than young adults in identifying the color of a cone behind them by looking over their shoulder. Even when older adults were successful in identifying the color of the cone, they more often made other task-related errors and used a different kinematic strategy than young adults.

3.1 Increased number of task-related errors in older adults

The shoulder check task was successful in 100% and 69% of the trials performed respectively by the young and older adults (Figure 2). For the older adults, placing one or both feet on the ground was observed as the most common error during the shoulder check task (22%), followed by cycling outside the lines (5%), and errors in identifying the color of the cone (5%). In addition, 15% of the healthy older adults lifted their pelvis from the saddle during the shoulder check task while all younger subjects remained seated.

Even when older adults performed the shoulder check successfully, they required more steering corrections than younger adults to remain stable and to continue cycling straight ahead while performing a shoulder check. We found that the standard deviation in steering angle in successful trials was larger in the young compared to the older subjects (Figure 2B, $t(62) = -3.73$, $p<0.001$, Cohen's $d=0.95$).

3.2 Increased torso rotation in the older adults

Older adults rotated significantly further with the torso with respect to the frame during the task than younger adults (Figure 3A, $t(62) = -6.28$, $p<0.001$, Cohen's $d=1.6$). The increased rotation of the torso with respect to the frame was caused by an increased rotation of the pelvis with respect to the frame (Figure 3B, $t(44) = -6.75$,$p < 0.001$, Cohen's $d = -2.04$) as we did not find any evidence for an age-related increase in the rotation of the torso with respect to the pelvis (Figure 3C, $t(44) = 1.50$,$p= 0.14$, Cohen's $d= -0.45$). As a result, older subjects required less rotation in the neck and/or smaller eye-head rotations than young adults to identify the color of the cone (Figure 3 D).

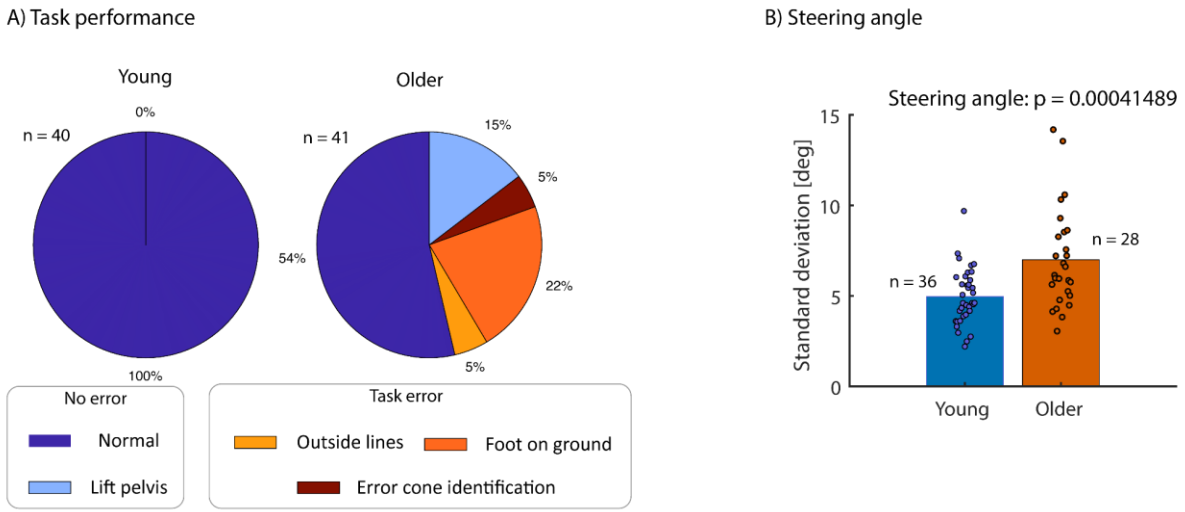

Figure 2: ***A.*** *100% and 69% of the trials performed respectively by the young and older adults were successful (no error).* ***B.*** *The standard deviation in steering angle was lower in the young compared to the older subjects (B).*

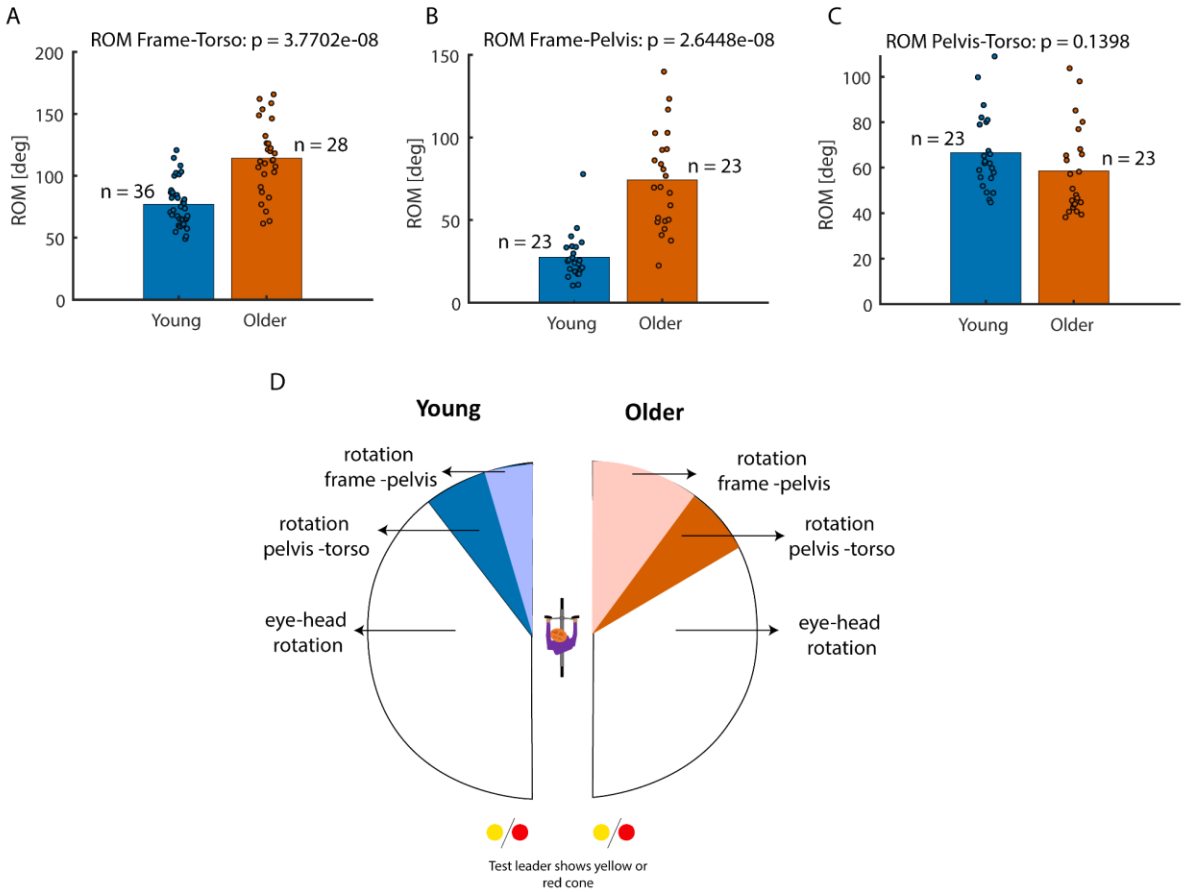

Figure 3: ***A.*** *Older subjects rotated more with the torso with respect to the frame than young adult during the shoulder check.* ***B.*** *Older adults rotated more with the pelvis with respect to the frame than young adults during the shoulder check.* ***C.*** *The range of motion of the trunk with respect to the pelvis was not different in young and older adults.* ***D.*** *The average differences in kinematics between young and older adults is illustrated in pane D. Differences in torso-frame rotations imply that young adults relied more on rotation in the neck and/or eye-head rotation to identify the color of the cones than older subjects. Note that we excluded data of several young on older subjects due to (1) an error in the task or (2) a faulty wireless connection between the IMU sensors on the handlebars, frame, pelvis and torso during the task (see details in method section).*

4. Discussion

Older cyclists were worse than young cyclists in performing a shoulder check. We asked participants to identify the color of objects behind them while controlling cycling direction. Even though our group of older cyclists was by no means representative for the oldest cyclists on the road as they were aged up to 65 years only, one third of them failed the task by either making cone-identification errors, interrupting cycling to prevent loss of balance, or cycling outside the lane while all young adults performed the task successfully (Fig. 2A). In addition, older subjects who performed the task successfully used more steering actions and rotated their torsos more with respect to the frame than young adults (Fig. 3). The observed differences in kinematic strategies between the group of young and older subjects show that even when older subjects could perform the task successfully, they had more difficulties in performing the concurrent tasks of object identification and controlling balance and cycling direction. The increase in variation in steering angle in the older subjects shows that they had to make more corrections to control the cycling direction or to control balance.

A first explanation for the increase in steering corrections is the different kinematic strategy used by the older subjects. Older subjects rotated more with the torso with respect to the frame, possibly to compensate for a decreased axial rotation range of motion in the neck and in eye-head rotation [22]. This is in agreement with research in car drivers where a reduced range of motion in the neck, and functional neck range of motion during the task, in older adults was associated with an increase in target detection errors during a shoulder check [23]. Yet, in contrast to our results in biking, older participants exhibited less trunk rotation to check the blind spot than younger participants when driving a car [23], which directly impacted their ability to detect a target. Reduced neck range of motion has also been identified as a risk factor for older car drivers [24] but this can be improved by training neck, shoulder and trunk flexibility [25,26].

Alternatively, given the mechanical coupling between the trunk and the arms, the increased trunk rotation in the older cyclists might cause undesired arm motion, which results in undesired steering. Additional steering corrections are most likely needed to compensate for the co-rotation of the trunk and arms to control balance and cycling direction. Note that the neck and head-eye rotations strategy used by the young subjects is mechanically not directly linked to arm motion and therefore undesired steering angles. Hence, the difference in kinematic strategies (increase in torso rotation) during the shoulder check task might explain the increase in steering angle variance, and potentially also the increase in balance loss during the task in the older subjects. Several studies found that inter-joint coordination was not impaired in older people, suggesting that older people can compensate for the passive dynamics due to their own movements as well as younger people [27].

A third potential explanation for the increase in steering corrections is a reduced ability in older subjects to estimate the position of the arms in the absence of vision. When turning the head, the arm and the steer are located outside of the field of view. Given the age-related decrease in proprioceptive acuity [16,28–30,but see 31–33], older adults rely much more on vision than on proprioception to control movements such as bimanual upper limb movements [34], reaching or grasping [35,36] or walking [37]. The preponderance of visual inputs to maintain a stable steer control would explain why older adults exhibit more steer variability when the gaze is away. The plausibility of this alternative is reinforced by the fact that, during car driving, a multi-tasking condition that took the gaze away from the road led the older adults to exhibit deviations from their trajectories similar to those observed in the current study [41].

Finally, the increase in steering variability and decrease in task performance could also stem from the decrease in dual-tasking abilities with aging [19,38,39]. The shoulder check task requires participants to simultaneously bike straight and look behind. During car driving, dual-tasking or multitasking made older participants drive in a more variable way than their younger counterparts [40,41]. Dual tasking during driving causes an increase reaction time to brake, sloppy steer control and worse distance estimation, especially in older adults [41–43]

We demonstrated that the ability to perform a shoulder check task already drastically decreased in adults aged 60 to 65 as compared to young adults. While we need to further understand the causes, this study could have direct policy implications. As shoulder checks are a common task while cycling, e.g. to safely interact with other road users, the reduced ability to perform a shoulder task while maintaining heading direction might contribute to the age-related increase in single-sided accidents [11]. Indeed, when cycling lanes are narrow,

deviations from the heading direction might cause cyclists to encounter changes in terrain (e.g. curbs, soft borders), which might cause them to lose balance. Our results raise awareness for balance threads imposed by shoulder checks in older cyclists, which might prompt policy makers to improve cycling infrastructure, such as wider cycling lanes that allow larger deviations in heading direction, individual cyclists to use assistive devices such as mirrors, or designers to develop new assistive devices that overcome the limitations of existing devices such as the limited field of view of bicycle-mounted mirrors.

5. References

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Appendix 1: details on conventional bike and ebike and sensor placement

The kinematics of the cyclist and bike was analyzed using inertial measurement units (IMU) mounted on the handlebars, frame, pelvis and torso (Figure Appendix 1). Cycling data of all subjects was collected while riding the same conventional and electrical bicycles, provided by the KU Leuven. Both bicycles were similar models with step-through frames. Only a small difference in frame height was present, with the frame of the electrical bicycle being slightly higher. The weight of the electrical bicycle was 27.7 kg, which was 7.9 kg heavier than the conventional bicycle. The electrical bicycle had a front wheel hub motor, and the battery was located above the rear wheel. Power support could be set to five levels. In the present study the third level was chosen, which can be described as normal support‘. Each bicycle had six gears, which were set on the fourth level. Participants were asked to not change these settings during the whole experiment. Participants could change the saddle height to a comfortable height. Wearing a bicycle helmet was mandatory.

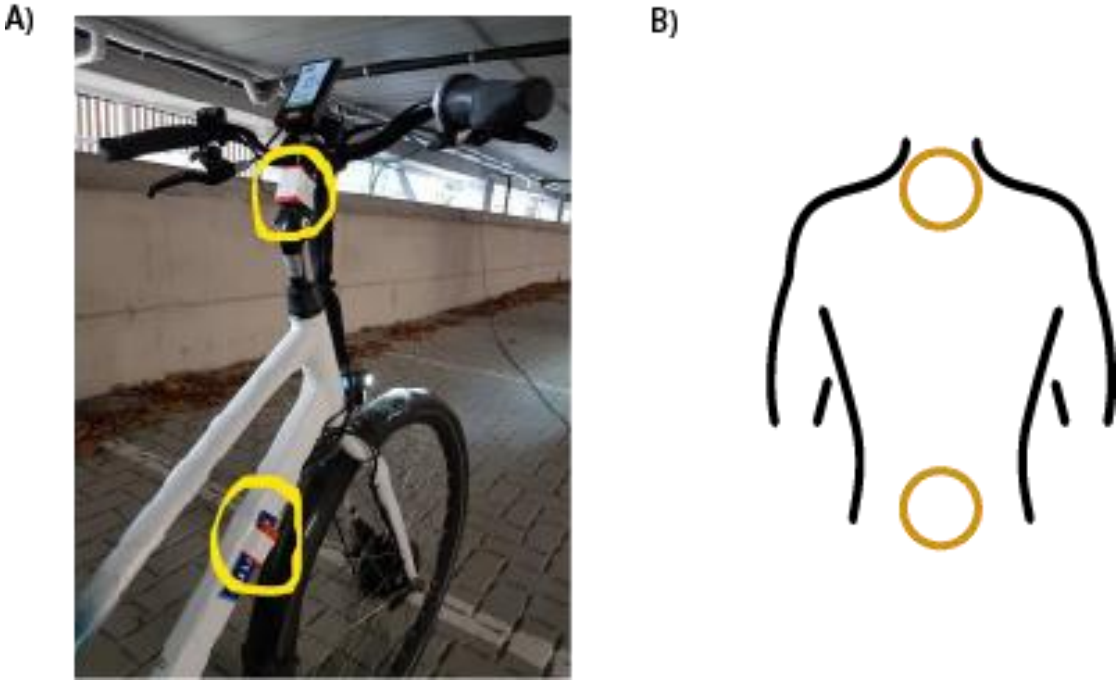

Figure appendix 1: IMU placement on the frame and handlebars of the bike (A) and on the pelvis and torso of the subject (B)

Appendix 2: Kinematic analysis for e-bike and conventional bike

We observed the difference between the young and older subjects in steering angle and ROM of the sensor was similar on the conventional bike and ebike during cycling in self-selected and slow speed conditions (Figure appendix 2).

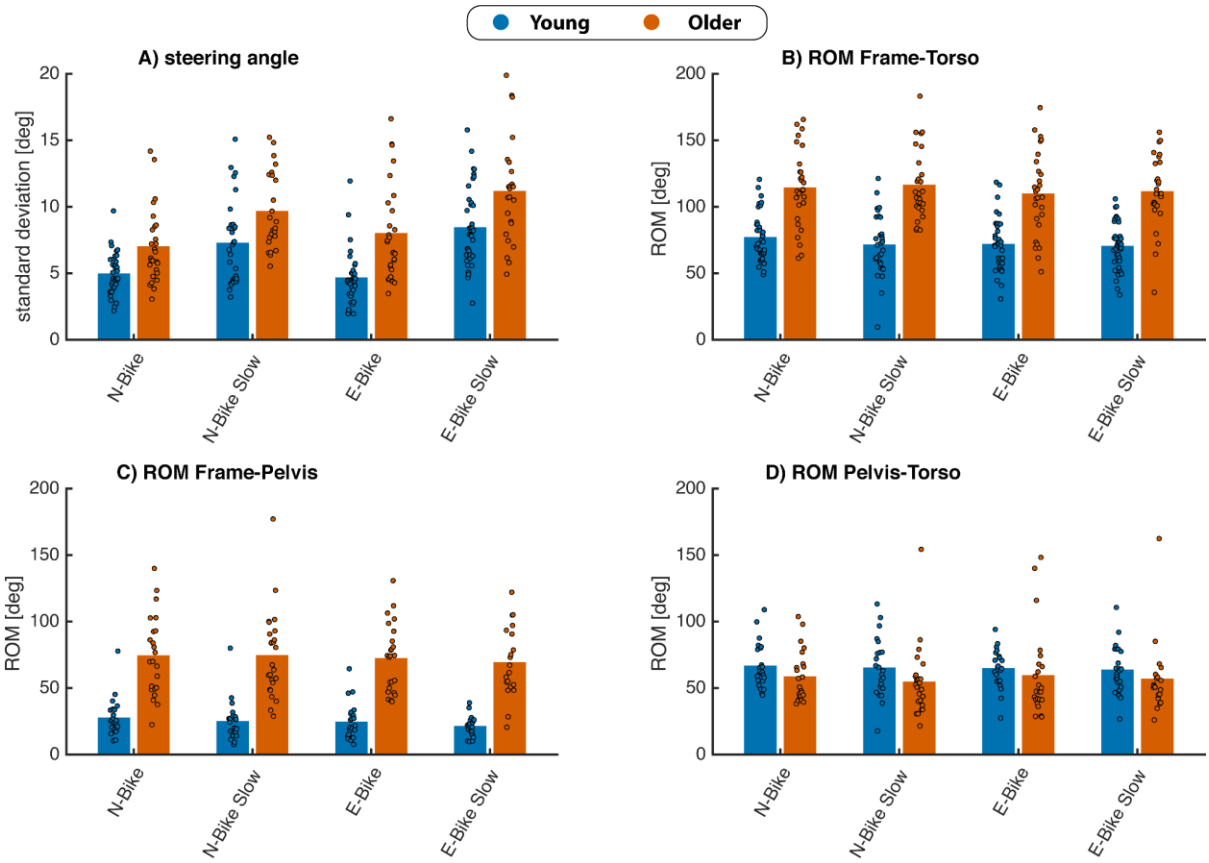

Figure appendix 2: *Standard deviation in steering angle (A) and range of motion between Frame and torso (B) frame and pelvis (C) and torso and pelvis (D) during the shoulder check task when cycling with a conventional bike (N-Bike) at preferred or slow (N-Bike Slow) speed or with an e-bike (E-Bike) at preferred or slow speed (E-Bike Slow). We observed that the effect of age on steering angle and ROM was similar for the conventional bike and e-bike at preferred and slower speed.*