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The co-contraction index of the upper limb for young and old adult cyclists

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ABSTRACT

Bicycling is a popular and convenient means of transportation amongst the elderly in the Netherlands. However, the uptake of the electric bicycle resulted in an increase of single-sided bicycle accidents amongst the elderly (Veiligheid, 2010). Since elderly are prone to severe injuries, bicycle stability is currently a popular research topic. Three main balance strategies have been proposed in former studies: steering as the primary balance strategy and trunk –and lateral knee movement as secondary balance strategies (Moore et al., 2011; Cain, 2013). Since steering is the primary strategy for bicycle stability, the stiffness of the arms plays an important role in active stability during cycling. It has been shown that the arm stiffness of a passive rider is an important factor on the stability of a bicycle (Doria and Tognazzo, 2014). In the study presented here, the co-contraction index (CCI) of the upper limb for young and old adult cyclist is studied. Data is collected during experiments based on the setup described in (Kiewiet et al., 2014), wherein contact forces, muscle activities and motions of the rider and bicycle are measured for 15 young adult (mean ± sd: 25.3 ± 2.8 yrs) and 15 old adult (mean ± sd: 58.1 ± 2.1 yrs) subjects during unperturbed and perturbed cycling. The arm stiffness is defined as a co-contraction ratio between muscle activity of the m. Biceps Brachii and m. Triceps Lateralis. Results suggest that older adult cyclists use more co-contraction of their arm muscles during cycling, compared to young cyclists. The inter-subject variability of the found CCI was higher for the old adult subject group, compared to the young group. The results support the initial hypothesis that the increase in co-contraction of the upper limb for older cyclists is higher during perturbed cycling compared to unperturbed cycling than for younger cyclists. The findings might give direction towards solutions for increasing the safety and stability for elderly cyclists.

1. Introduction

Bicycling is a popular and convenient means of transportation amongst the elderly in the Netherlands. With the introduction of the electric bicycle, elderly cyclists can continue cycling at a later age. Electrically assisted bicycles lead to less physiological stress and reduced lower extremity muscle strains (Theurel et al., 2012). However, the increased use of the bicycle amongst the elderly resulted in an increase of single sided bicycle accidents (Veiligheid, 2010). Half of the single-sided bicycle accidents have been shown to be behavioural related (Ormel et al., 2009), indicating that often a steering error is the onset for the instability. Secondly, unexpected change in environment or perturbations can result in undesired steering motions. Since the elderly are prone to severe injuries, bicycle stability is currently a popular research topic (Schwab and Meijaard, 2013). Three balance strategies have been proposed in former studies: steering as the primary balance strategy and trunk - and lateral knee movement as secondary balance strategies (Moore et al., 2011; Cain, 2013). Since steering is the primary balance strategy, the stiffness of the arms plays an important role in active stability during cycling. It has been shown that the arm stiffness of a passive rider has a high influence on the stability of a bicycle (Doria and Tognazzo, 2014).

In the study presented here, muscle activations of various upper limb muscles of young and old adult cyclists are investigated during cycling under unperturbed and perturbed conditions. Two antagonistic muscles that span the elbow joint are used to define a co-contraction index (CCI) of the arm: the mono-articular lateral triceps brachii and the bi-articular muscle biceps brachii. Co-contraction implies simultaneous activation of multiple

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counter-acting muscles. Co-activation of counter-acting muscles result increase the joint stiffness, making it more difficult to perturb the joint (Kornecki et al., 2001). Other muscles activations studied are that from the posterior part of the deltoid muscle, the pectoralis major muscle, the teres major muscle and the latissimus dorsi muscle. These muscles actively assist in shoulder girdle movement. Therefore, these muscles might be actively used during steering corrections.

Muscle activities during cycling are studied frequently (Theurel et al., 2012; Hug and Dorel, 2009). However, they are primarily restricted to the lower extremity muscles. To our knowledge, no study has concentrated on muscle activity involving arm movement during bicycling. Studies have concentrated on muscle dynamics during vehicle steering tasks, but these are often based on steering wheels and simulators (Pick and Cole, 2007; Abbink et al., 2011).

Physical limitations of elderly cyclists are an adjoining cause for the age-related increase of single-sided bicycle accidents (Ormel et al., 2009). It is well known that the decrease of muscle strength is age-related (Mitchell et al., 2012). Furthermore, Inglin and Woollacott (1988) showed that prime mover muscle response onset latencies of the upper arm showed a large, significant increase in older adults compared to younger subjects. This suggests that the speed of voluntary movement is delayed due to an increased latency of the onset of the voluntary muscle response. When extrapolating these findings to bicycling, this indicates that elderly possibly experience more difficulties in faster voluntary steering corrections. Allum et al. (2002) found that ageing plays an important role in the delayed onset of automatic balance correcting muscle actions.

In the age group of 55 and over, cyclists become often more frightened of other participants of traffic and are more easily distracted (Ormel et al., 2009). Participating in traffic demands dual motor- and cognitive tasks. It has been shown that elderly experience more difficulties in dual motor- and cognitive tasks than younger adults (Seidler et al., 2010). Vlakveld et al. (2014) reported that an increase of the accident risk of elderly cyclists on electric bicycles may be a result of a relatively higher mental workload for elderly cyclists (65+ yrs) compared to a middle adulthood reference group (30–45 yrs). Bulsink et al. (2016) showed differences in cycling strategies for both time -and frequency domain between younger cyclists (20–30 yrs) and older cyclists (54–62 yrs). This suggests that old adult cyclists possibly experience more difficulties during cycling under perturbed conditions than younger subjects. We therefore hypothesize that the increase in co-contraction of the upper limb for old adult cyclists is higher during perturbed cycling compared to unperturbed cycling than for the young adult cyclists.

2. Method

2.1. Data collection

Data is collected during experiments performed in a laboratory setup based on the setup described in (Kiewiet et al., 2014), wherein contact forces, muscle activities and motions of the rider and bicycle are measured for 15 healthy old adult (mean ± sd: 58.1 ± 2.1 yrs, 75.8 ± 7.7 kg, 1.79± 0.07 m) and 15 healthy young adult (mean ± sd: 25.3 ± 2.8 yrs, 68.4 ± 8.5 kg, 1.75 ± 0.17 m) subjects during unperturbed and perturbed cycling. Fig. 1 displays a schematic overview of the experimental setup. Within the setup the rear wheel is located on a roller bench and the front wheel on a treadmill to preserve the tire-road contact. The roller bench is situated on a 6 D.O.F. Stewart platform to apply perturbations. Safety measurements were taken to secure the safety of all subjects, without interfering their performance. All subjects are experienced

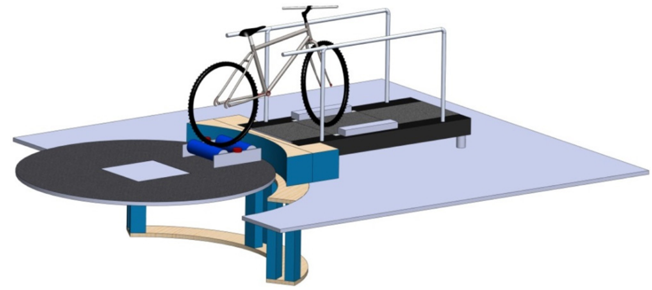

Fig. 1. Schematic overview of the experimental setup. The rear wheel is located on a roller bench and the front wheel on a treadmill to preserve the tire-road contact. The roller bench is situated on a 6 D.O.F. Stewart platform to apply lateral perturbations.

Table 1
Measured muscles during the experiments and the movements to which they primarily contribute during cycling tasks.

Muscle	Prime Involving Movement
Lateral Triceps Brachii	Elbow extension
Biceps Brachii	Elbow Flexion

cyclists and use a bicycle on daily basis. Every subject gave their written informed consent. The study was approved by the local medical ethical committee. Subjects are instructed to cycle without an imposed predefined path, generally in longitudinal direction of the treadmill. The experiments were only conducted when the subject felt comfortable with the bicycle and cycling stationary on the setup. The instrumented bicycle used is a low step Trek L200 city bicycle with a straight handlebar. Data is collected at a velocity of 4 m/s. All cycling trials consisted of 100 s of unperturbed cycling and 100 s of perturbed cycling. The pedal frequencies and gears are imposed to ascertain equal velocities of the treadmill-powered front- and human propelled rear wheel. All subjects were capable to comply with the imposed pedal frequency. The gear was fixed at 4 whereas the imposed pedal frequency was set at 0.87 Hz.

2.2. Perturbation

Two types of perturbations are applied during the experiments by means of a Stewart platform: a lateral pulse and a continuous lateral multisine perturbation. The lateral pulse consisted of 2 cm lateral translation of the Stewart platform in 0.2 milliseconds. The lateral pulse is given 5 s prior to the continuous lateral multisine perturbation. The actuation signal used for the continuous lateral perturbation is a multisine consisting of 10 different frequencies: 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.8, 2.2, 2.6 and 3.0 Hz. A multisine is unpredictable for the subjects, thereby preventing anticipation of the subject to the perturbation. The multisine signal consisted of 10 times a period of 10 s. The perturbations served to imbalance the subjects. Old adult subjects experienced sufficient imbalance with lower perturbation amplitudes than young adult subjects. Therefore, the younger subjects are imposed to an perturbation amplitude of 2.00 cm whereas the older subjects are imposed to a perturbation amplitude of 1.75 cm for safety precautions. The amplitude of the perturbation is adjusted if necessary.

2.3. Muscles

For concise grounds, the muscle activations of only several left-hand side muscles have been measured during the cycling trials. The muscles and movements to which they primarily contribute, and therefore presumably during cycling tasks, are listed in Table 1. Maximal voluntary isometric contraction (MVIC) of the lateral triceps brachii and biceps brachii are captured to normalize their

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