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The influence of age, muscle strength and speed of information processing on recovery responses to external perturbations in gait

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ABSTRACT

Dynamic imbalance caused by external perturbations to gait can successfully be counteracted by adequate recovery responses. The current study investigated how the recovery response is moderated by age, walking speed, muscle strength and speed of information processing. The gait pattern of 50 young and 45 elderly subjects was repeatedly perturbed at 20% and 80% of the first half of the swing phase using the Timed Rapid impact Perturbation (TRiP) set-up. Recovery responses were identified using 2D cameras. Muscular factors (dynamometer) and speed of information processing parameters (computer-based reaction time task) were determined. The stronger, faster reacting and faster walking young subjects recovered more often by an elevating strategy than elderly subjects. Twenty three per cent of the differences in recovery responses were explained by a combination of walking speed ($B = -13.85$), reaction time ($B = -0.82$), maximum extension strength ($B = 0.01$) and rate of extension moment development ($B = 0.19$). The recovery response that subjects employed when gait was perturbed by the TRiP set-up was modified by several factors; the individual contribution of walking speed, muscle strength and speed of information processing was small. Insight into remaining modifying factors is needed to assist and optimise fall prevention programmes.

1. Introduction

The rapidly increasing elderly population is associated with an increasing incidence of falls, which has serious consequences for both the individual and the health care system [1]. Near falls, such as trips, are relevant markers of fall risk [2]. They account for approximately 59% of the falls in elderly subjects [3]. A near fall is defined as a temporary disturbance in dynamic balance which is caused by external perturbations. Healthy individuals have remarkable capacity to counter the forward momentum of the centre of mass which results from an external perturbation, by a concerted action of the perturbed leg and supporting leg [4,5]. In general two recovery strategies have been identified, either the obstructed leg is placed on the ground immediately after being perturbed while a recovery step is taken with the contra-lateral leg (lowering strategy, LS), or the obstructed leg can be elevated after being perturbed in order to continue walking (elevating strategy, ES).

Previous studies have shown that the choice for the recovery response depends on perturbation characteristics, e.g. perturbation duration [6] and obstruction timing in the gait cycle [4–9]. For instance early swing perturbations mainly evoke ES, while late swing perturbations mainly evoke LS. Interestingly, similar perturbation conditions yield different recovery responses in young and elderly subjects [8,9]. Studies have shown that elderly subjects recover more often by LS [8,9], which has been attributed to (for example) an impaired limb positioning and reduced lower limb strength [9]. Moreover studies have found that elderly subjects are less successful in their recovery, as indicated by higher failure rates, defined as taking additional steps, having secondary contact with the obstacle and even fall events. For instance the study of Pijnappels et al. showed that young subjects recovered successfully from mid swing perturbations by ES, while elderly subjects used ES and LS to recover from identical perturbations, but failed more often in their recovery [8]. The less adequate recovery responses in elderly subjects have been associated with age related physiological changes such as lower peak moments, poorer placement of the recovery limb, and reduced response time

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[4,6,8–12]. Most studies on balance recovery focus on success/failure rates. They are conducted on small groups and tend to rely on limited amounts of perturbation and therefore investigate mainly a single physiological aspect at a time. For instance, Schillings et al. investigated muscular responses during stumbling over obstacles [4] and Lamoureaux et al. examined the effect of muscle strength on obstacle negotiation [10]. In daily life, elderly subjects have to deal simultaneously with several age related physiological changes such as an impaired speed of information processing and reduced muscle strength. Currently it is unclear how these changes and the combined effect of these changes are associated with recovery responses. It is hypothesised that there is a graded response to external perturbations, where physiological deterioration is initially coped with by relying on the LS and changes in gait. In later stages, failure to recover is expected to become more prominent. The current study aims to investigate how the recovery response to external perturbations in gait is moderated by age, walking speed, muscle strength and speed of information processing, relying on a sizable population of young and elderly subjects and a large number of controlled perturbations.

2. Materials and methods

2.1. Subjects

Fifty healthy young (23 M/27 F, 24 ± 4 years) and 45 healthy elderly (20 M/25 F, 67 ± 6 years, Table 1) subjects were included. Exclusion criteria were cardiac problems, breathing problems, diabetes, neurological diseases, hearing or sight impairments, use of psychoactive or sedative medication, use of a walking aid, unable to walk, or Tinetti score <24 indicating risk for falling. The study was approved by the local ethical committee; all participants were informed and signed informed consent was obtained before participating.

2.2. Measurements and outcomes

2.2.1. TRiP experiment

The 'Timed Rapid impact Perturbation' (TRiP) set-up, a specially designed trip set-up consisting of a treadmill (Medifit) equipped with a safety harness and two pneumatic braking devices, was used to induce perturbations in a standardised way (Fig. 1) [13]. The TRiP can perturb the swinging leg at specific instants during the first half of the swing phase, with specific blocking durations and perturbation forces, thereby triggering LS and ES (online supplement [13]). A fixed protocol was used to induce 10 perturbations at 20% (early swing perturbations) and 10 perturbations at 80% (mid swing perturbations) of the first half of the swing phase (Fig. 2). Perturbations were equally distributed over both legs, had a fixed duration of 150 ms and were induced with a fixed braking pressure of 3 bar. The time between successive perturbations was sufficient to enable subjects to regain their normal walking pattern. Video recordings were used to assess the recovery strategy. A pilot study on 300 perturbations showed that this assessment method had an overall agreement of 93% between instructed observers. The proportion of perturbations recovered by an ES (%) assessed over the complete experiment was used as a measure for the recovery response.

Prior to the TRiP experiment, subjects walked a 20 m straight distance to determine their comfortable walking speed. This speed was used during the TRiP experiment as a faster or slower speed may have an effect on the recovery response [13]. Moreover before the experiment, subjects walked 2 min on the treadmill, first without and subsequently with the TRiP to become accustomed to the set-up. Comparing the gait of five young and five elderly subjects using acceleration-based gait analysis showed no significant differences in gait between overground walking and treadmill walking, neither between treadmill walking with and without the TRiP (results not shown).

2.2.2. Muscular factors

Isometric knee extension and flexion strength was measured using a dynamometer (Biodex III) [14,15]. Subjects were seated with their hip and knee in 90° of flexion and were asked to successively produce maximal isometric knee extension and flexion contractions as fast as possible, while maintaining maximal force for 5 s. Only the right leg was tested [16]. Maximum knee flexion and extension moments and the rate of moment development (RMD), defined as the percentage of the maximum moment attained 200 ms after the start of the contraction was determined [14,15]. All participants were consistently verbally encouraged.

2.2.3. Speed of information processing factors

Speed of information processing was determined using a computer-based four-choice finger-cuing reaction time task [17]. Subjects were seated behind a computer with the index and middle finger of both hands on specific keys on the bottom row of the keyboard. A row of four squares was continuously visible in red outlines on the computer monitor, while two conditions were presented. Within the un-cued condition, all the four squares were coloured red, and after an interval of 100, 250, 500, 750 or 1000 ms, one of these four squares was coloured green. In the cued condition, only two out of the four squares (either the two left most or the two right most) were coloured red, and after one of the above mentioned intervals, one of the non-red squares was coloured green. The cue indicated the preparation of the response hand opposite to the location of the cue. Subjects had to respond as quickly and accurately as possible by pressing the key that corresponded to the green coloured square on the screen. At the

Table 1
Averages ± standard deviation [ranges] for subject characteristics, tinetti scores, speed of information processing and strength measures for young and older subjects.

	Young ($n = 48$)	Elderly ($n = 43$)	p-Value
Age (years)	24.4 ± 4.0 [18–36]	67.4 ± 6.2 [60–82]	0.00*
Height (m)	1.76 ± 0.09 [1.60–1.94]	1.70 ± 0.10 [1.48–1.92]	0.00*
Body mass (kg)	69.7 ± 10.3 [50.0–92.0]	74.1 ± 12.2 [43.0–100.0]	0.64
Tinetti score	28.0 ± 0.0 [28–28]	26.9 ± 1.4 [24–28]	<0.01*
Max. flexion (Nm)	90.0 ± 30.1 [36.6–162.6]	60.6 ± 22.8 [24.5–148.2]	<0.01*
RMD flexion (%)	62.8 ± 19.3 [25.4–97.7]	39.1 ± 17.6 [8.6–81.3]	<0.01*
Max. extension (Nm)	232.8 ± 73.7 [114.0–392.2]	166.0. ± 51.6 [84.8–270.4]	<0.01*
RMD extension (%)	44.7 ± 20.3 [4.5–86.0]	26.8 ± 21.2 [4.3–85.4]	<0.01*
Avg. reaction time (ms)	360.0 ± 32.7 [297.5–437.5]	534.8 ± 82.1 [377.9–820.7]	<0.01*
Cognitive flexibility (ms)	136.3 ± 56.9 [15.0–269.0]	51.9 ± 136.6 [−280–370]	<0.01*
Walking speed (km/h)	4.9 ± 0.6 [3.7–6.0]	3.8 ± 0.6 [2.7–5.5]	<0.01*
Quality of recovery response (% perturbations recovered by ES)	31	21	<0.01*

* Significant difference ($p < 0.05$).