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Visuo-locomotor coordination for direction changes in a manual wheelchair as compared to biped locomotion in healthy subjects

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HIGHLIGHTS

- Anticipatory head movement found for both wheelchair and biped locomotor modes.
- Specific gaze behavior depends predominantly on the environmental demands.
- Manual wheelchair navigation combines both biped and vehicular-based control.

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ABSTRACT

The visual system during walking provides travel path and environmental information. Although the manual wheelchair (MWC) is also a frequent mode of locomotion, its underlying visuo-locomotor control is not well understood. This study begins to understand the visuo-locomotor coordination for MWC navigation in relation to biped gait during direction changes in healthy subjects. Eight healthy male subjects (26.9 ± 6.4 years) were asked to walk as well as to propel a MWC straight ahead and while changing direction by 45° to the right guided by a vertical pole. Body and MWC movement (speed, minimal clearance, point of deviation, temporal body coordination, relative timing of body rotations) and gaze behavior were analysed. There was a main speed effect for direction and a direction by mode interaction with slower speeds for MWC direction change. Point of deviation was later for MWC direction change and always involved a counter movement (seen for vehicular control) with greater minimal distance from the vertical pole as compared to biped gait. In straight ahead locomotion, subjects predominantly fixed their gaze on the end target for both locomotor modes while there was a clear trend for subjects to fixate on the vertical pole more for MWC direction change. When changing direction, head movement always preceded gaze changes, which was followed by trunk movement for both modes. Yet while subjects turned the trunk at the same time during approach regardless of locomotor mode, head movement was earlier for MWC locomotion. These results suggest that MWC navigation combines both biped locomotor and vehicular-based movement control. Head movement to anticipate path deviations and lead steering for locomotion appears to be stereotypic across locomotor modes, while specific gaze behavior predominantly depends on the environmental demands.

1. Introduction

Steering or changing direction towards a new intended travel path while walking requires sensory-motor coordination to reorient the body while still maintaining balance [1]. The visual system is a crucial part of steering because it provides spatio-temporal information about the desired travel path and general movement within the environment. There are many other ways to locomote through the environment including wheeled mobility (e.g., bicycles, scooters, wheelchairs and motorized vehicles). Yet while biped locomotion has been studied for a variety of navigational tasks (e.g., stepping over or circumventing obstacles, changing direction), there is less research on the strategies used for other locomotor modes and very little for manual wheelchair (MWC) locomotion. The MWC is a mode of self-propelled wheeled locomotion that is used frequently [2] but its underlying visuo-locomotor control which involves very different head movement as compared to biped or other seated locomotion is still not well understood. In this study, we will focus on navigating

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to a new direction for comparing biped and MWC locomotor modes.

For biped gait, steering involves a top-down sequence of body reorientation, starting with a rotation of the eyes and head towards the new travel path followed by the trunk and then the feet [1,3–5]. The anticipatory head movements are considered important to prepare and pre-programme adaptations within two steps prior to path deviations [6]. Specifically, it is suggested that these head movements provide an allocentric reference frame to re-orient the body [3] and steer towards the new direction of travel [7]. During adaptive locomotion, common characteristics of gaze behavior show that the majority of fixations are either directed towards a desired future path or an object of interest [4,8]. Moreover, prior to a direction change, individuals invariably make saccadic eye movements towards the end-point of the travel path, which allows the identification and extraction of information concerning the future path [4].

There are surprisingly few studies to understand the visuo-locomotor coordination underlying MWC navigation, specifically during direction changes. However, Higuchi et al. [9] did compare biped and MWC locomotion, with respect to aperture perception in order to pass through doorways. They showed that able-bodied subjects underestimated their extended spatial requirements in a MWC, even after some practice, whereas they overestimated it when walking. The authors concluded that adaptation to altered body dimension is likely to occur very quickly under a familiar form of locomotion [9]. Higuchi et al. [10] also showed that while propelling a WC, able-bodied subjects tended to fixate more frequently on door edges, compared to walking. The authors suggested that the novelty of the locomotion mode caused participants to be more concerned about avoiding a collision with the door [10].

Although a MWC is not a car and does not have the constraints of a road environment in a high-speed context, it is a wheeled vehicle and may involve similar visually based navigational behavior. Land [11] likened the control of making right angle turns in a car to walking in that there is an anticipatory orienting head movement followed by the compensation for the head turning on the body within the car. It was also suggested that when turning a car along a curved road, drivers appear to focus on a tangent point on the inside of the curve of the road 1–2 s before turning [12]. Wilkie et al. [13], however, suggested the use of the tangent point was speed related and proposed a general strategy of «looking where you want to go» through gaze fixations onto points of the road at 1–2 s ahead. This is part of an active gaze theory proposed by Wilkie and Wann [14]. Finally, Land et al. [11] clearly showed that the car makes a counter-movement in the opposite direction before turning along a curved road.

MWC locomotion involves speeds that are more comparable to walking and thus allow us to compare the visuo-locomotor control between these two modes of locomotion. However, the MWC implies very different propulsion means with the involvement of upper body movement. Given that the MWC is also a common mode of locomotion for many people, it will be interesting to understand the relation to premorbid bipedal behavior for those now using a MWC. As a first important step, the goal of this study was to begin to understand the visuo-locomotor coordination for MWC navigation in relation to biped gait when changing direction in healthy subjects.

2. Material and methods

2.1. Participants

Eight able-bodied adult male participants (mean age: 26.9 ± 6.4 years; height: 1.8 ± 0.1 m; mass: 76.5 ± 12.7 kg) were recruited. Ethics approval was obtained from the Quebec City Rehabilitation Institute and all participants provided written informed consent. Subjects with any self-reported neurological or musculoskeletal problems or a score below 20/20 on the Snellen visual acuity test were excluded.

2.2. Data collection

A motion analysis system (four Optotrak Certus motion sensors, NDI, 120 Hz) and seven triads of non-colinear infra-red markers (head, sternal notch, wrists, feet and on the MWC frame) were used to assess body and MWC movements. Gaze behavior data were collected using a commercial eye tracker (Mobile XG from Applied Sciences Laboratories, 30 Hz) that was synchronized with the Optotrak system.

2.3. Protocol

Participants were trained for up to 20 min in the MWC (Quickie Q7 from Sunrise Medical) using some tasks of the Wheelchair Skills Training Program (www.wheelchairskillsprogram.ca). Subjects had to roll forwards (100 m), roll backwards (5 m), turn 90° (right and left) while moving forwards and backwards, turn in place (180°) as well as ascend and descend a 5° and 10° incline. Then participants were asked to perform two experimental conditions, walking first and then propelling the MWC, both at comfortable self-selected speeds: (1) straight ahead along an 8.75 m path (SA condition) and (2) changing direction (CD condition) 45° to the right off the original straight ahead pathway at a specific point four metres from the start position as indicated by a black vertical pole (VP; 1.86 m height, 3.5 cm diameter). A round target was placed at the end of both paths and subjects were instructed to walk or propel the MWC to it. A corridor (0.92 m wide, 1.85 m long) was placed at the starting point to indicate an initial straight propulsion zone (see below). The vertical pole used for the CD condition was aligned with the right boarder of this corridor.

2.4. Data analysis

Five trials were analysed per condition. Dependent variables analyzed during the approach phase (end of corridor to the mid-point of VP crossing) were: (1) average forward speed of the trunk (walking) or centre of the MWC axel, (2) minimal clearance (distance between the wrist and the VP), (3) point of path deviation of the centre of mass of the trunk (walking) or MWC trajectory, (4) temporal coordination of angular deviations for the eye, head, trunk and MWC towards the new direction in relation to the SA condition and (5) relative timing between segments as the difference in temporal coordination between eye-head, head-trunk, and trunk-WC. Video data were coded using software (PhysMo Video motion analysis) that allowed a frame-by-frame analysis of gaze behavior (location and duration at every frame for each trial; 30 Hz.). Gaze behavior (see Hollands et al., 2002) was categorized as: a) fixations on a location or object within the scene (≥3 frames) specifically: the vertical pole (VP); the target; and other environmental features (OEF) b) travel fixation which is defined as a gaze that stabilizes at a constant distance in front of the participant and moves with the subject (≥3 frames) or (c) other non-fixations (ONF), which include saccades as rapid eye movements causing a shift in gaze between two locations (≥1 frame), head initiated gaze shift where the eye and head turn together, blinks or undetermined data. The proportions of each gaze behavior as a percent of total behavior was then calculated and mean values reported.