Visual Sampling Characteristics during Quiet Standing and Walking in an Individual with Peripheral Neuropathy

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Abstract

The purpose of this study was to investigate the contribution of vision to the maintenance of balance while standing and walking in an individual with peripheral neuropathy. FS, a young man (33 yrs), has hypertrophic neuropathy type Dejerine-Sottas with compromised balance. We studied this individual performing two tasks; quiet standing and normal straight path walking. In both tasks he wore LCD goggles comprising lenses that were normally opaque (excluding vision) but that became transparent when he operated a hand-held switch. He was instructed to use vision when and if needed. Visual sampling characteristics (timing and duration) during the two tasks were analyzed. The results suggest that it is possible to use vision in the place of proprioception to control static and dynamic balance but that this places an extreme demand on the visual system.

1. Introduction

The three major sensory systems, visual, vestibular and kinesthetic, provide critical information for the control of gait, posture and balance. One approach to understanding the specific contribution and relative weighting of information from each system is to systematically manipulate/eliminate sensory information from each modality and categorize changes in performance [1,2]. Another approach is to study patients who have specific deficits in sensory systems [3,4].

This study was designed to investigate the control of gait, posture and balance in an individual with peripheral neuropathy. It has been shown that loss of sensory information from the limbs can adversely affect the control of static and dynamic balance [4], but information from other sensory systems (particularly vision) can compensate for this loss. Since the three sensory systems provide a degree of overlapping information (such as orientation of the body with respect to the vertical) it is not surprising that loss of information from one sensory modality can be compensated for, at least to some extent, by the other two. However, to date, no attempt has been made to quantify the increased demand placed on the visual system when one of the other two sensory systems is compromised. This is the focus of this paper.

2. Methodology

2.1 Patient Information

The patient's Dejerine Sottas profile has the following relevant characteristics:
(a) Slow development of early motor skills (walking developed only after the age of 3 years)
(b) Severe sensory problems: peripheral nerve conduction velocities significantly lower than normal (~12 to 15 m/s in proximal areas, less than 12 m/s in distal regions of upper and lower limbs. No evoked conduction could be detected in the branches of the left common-peroneal nerve).
(c) Arm and leg areflexia (including total absence of patellar reflex).
(d) Pupilary hyporeflexia.
(e) Progressive hearing loss.
(f) Severe club feet corrected surgically at the age of 17 (surgery included double-arthrodesis of both left and right ankle joints). Left ankle still has an implanted degree of freedom-limiting clip.
(g) Weakness in distal muscles (much worse in feet than in hands).
(h) Peak neuropathy progression from the age of 8 to 15. Slower progression since then. Evoked conduction has been recently observed in the left arm (three years ago) in nerves that did not respond ten years ago (but this may stem from poor testing ten years ago).
(i) Using a cane for two years only, especially at night.
(j) No medication to treat the disability (none exists for this condition yet). Physical therapy sessions have been undertaken sporadically through the years.

2.2 Experimental Protocol

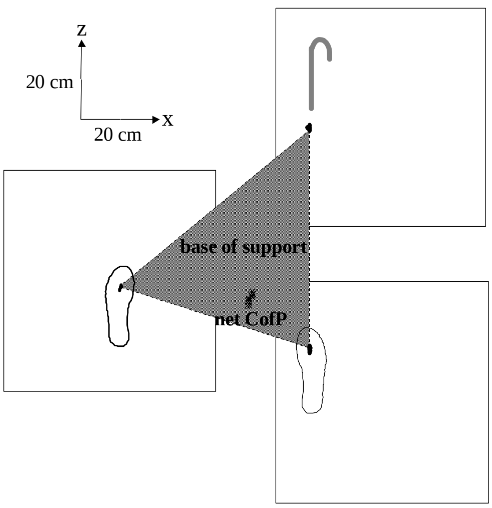
FS was asked to perform two tasks. The first task involved standing quietly for two minutes with each of his feet and his cane positioned on separate force plates. The layout of the three force plates is shown in Figure 1. The second task required him to walk along a 6.5 m straight path.

In both experimental tasks FS wore liquid crystal eye glasses. These glasses were normally opaque allowing no information about form or motion of objects. When a current was passed through the liquid crystal lenses, they become transparent. FS used a hand-held switch to control the current through the lenses and was instructed to use vision when and if he needed. Therefore FS had complete control of acquisition of visual information. The switch signal indicating when, and for how long FS visually sampled was collected at a sampling frequency of 256 Hz. The number and the total duration of visual samples taken during the two tasks were analyzed. In addition to the intermittent visual sampling trials, data for control standing and walking trials in which vision was permanently available were collected.

2.3 Data Analysis

2.3.1 Standing task

From the force plate data, centre of pressure (COP) under each of the two feet and the cane was calculated. The spatial path of the COP under each foot and cane for one trial is shown in Figure 1.



From this data the effective base of support (area of the triangle connecting instantaneous COP co-ordinates for the two feet and cane) was calculated. Net centre of pressure was calculated from the weighted sum of the individual centre of pressure profiles [5].

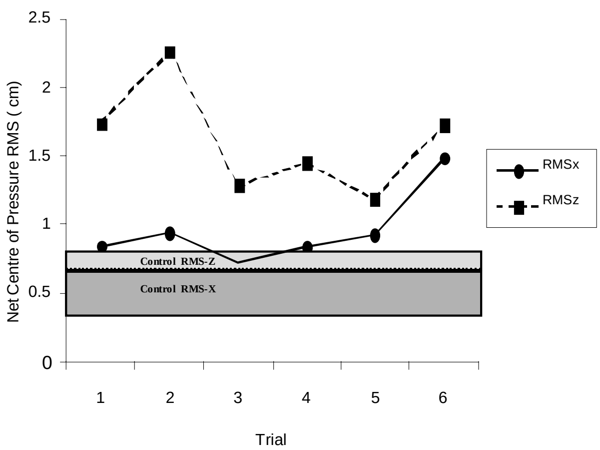
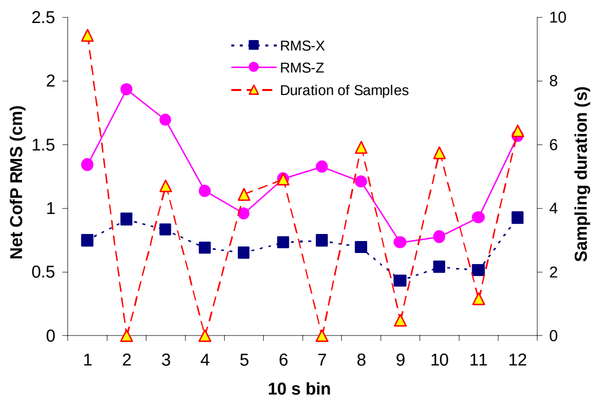


Figure 2. shows the net COP RMS in both the z (anterior-posterior) and the x (medial-lateral) planes for each of the six test trials in which FS had control of the LCD glasses. The shaded areas show the range of values obtained from control trials in which FS had vision throughout (LCD glasses permanently transparent).

Data for each trial was separated into twelve 10 s bins to allow analysis of changes in stability and visual sampling over the duration of the two minute trial.

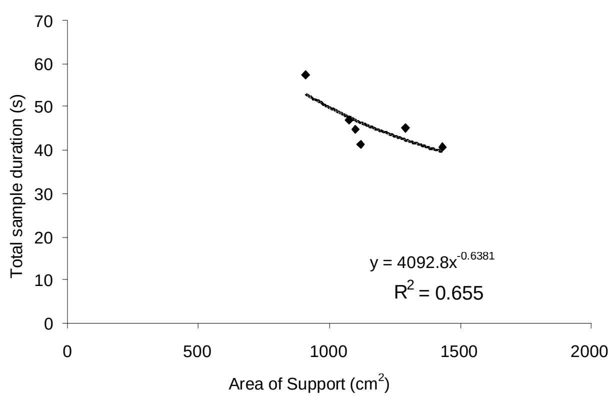
Figure 3 shows the results from a single trial of the net COP RMS (of both the x and z plane) together with the mean duration of visual samples taken in each 10 s time period.



Cross-correlation analysis between the net COP RMS and the number and duration of visual samples taken during each 10 s time period was carried out to determine if the visual sampling pattern changed as a function of COP excursions. Additional cross-correlation was performed to determine if visual sampling changed as a function of COP variation during the *preceding* 10 s period.

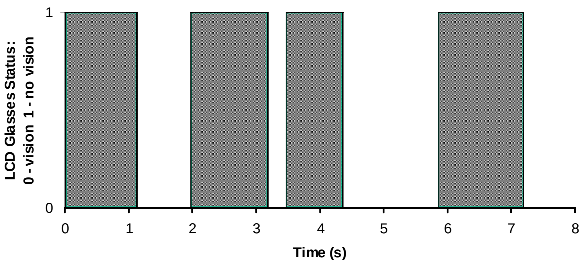
Prior to the start of each trial FS adjusted his position on the force plates until he felt stable. Therefore, the starting positions of his feet and cane were different for each trial resulting in a different area of support.

Figure 4 shows the relationship between the total duration of visual samples and the area of support.



2.3.2 Walking task

Figure 5 shows raw data obtained from the LCD glasses for a typical visual sampling walking trial. The number and the total duration of visual samples was determined for each trial.



3. Results

The average time spent visually sampling during standing was 38.4 % (range: 34% to 47.9%), and during walking was 61% (range: 40% to 70.5%) of the travel time. Number of visual samples during standing ranged from 7 to 20, and during walking from 3 to 5.

During standing the centre of pressure records showed higher than normal deviation in both planes when compared with control trial data where vision was available throughout.

There was a significant correlation between the total sample duration over a trial and the area of support for that trial. FS took proportionally fewer visual samples as the area of the base of support increased.

There were no significant correlations between the magnitude of net COP excursions and both frequency and duration of visual sampling.

4. Discussion

4.1. Control of upright stance

Standing upright is not a challenging task for healthy individuals, and recently we have shown that balance can be regulated by the stiffness of the ankle joint [6]. In healthy individuals, presence or absence of vision does not have any appreciable impact on the ability to stand upright: standing without vision for two minutes poses no problem. However, FS, an individual with severe peripheral neuropathy, was unable to stand without vision for two minutes. The results of these experiments provide a measure of the demands placed on the visual system for standing when lower limb proprioception is absent; on average visual information was needed for 40% of the trial duration to maintain stability. This does not however keep the deviations of the COP within the same range as the control trials. This increase has to be put in context; during quiet standing COP excursions are nowhere near the limits of stability. In this case the increased base of support due to using the cane, provides the COP with greater freedom to deviate before threatening stability.

What triggered FS to visually sample is not known. Since vision is critical for maintaining stability in the patient, visual sampling cannot be attributed to random factors. One possibility is that the nervous system monitors the net COP and triggers a visual sample when it deviates beyond some threshold. Our analyses did not support such a control strategy: the number and pattern of visual samples did not correlate with the magnitude of COP variation as it changed over time. It is possible that the nervous system monitors parameters other than COP in determining when to take a visual sample.

4.2. Control of balance during walking

Vision provides unique information about the environment, self-motion and movement of the body segments that is critical for the control of locomotion [7]. A consistent observation is that while vision is important, continuous vision is not a pre-requisite for safe locomotion. Intermittent visual sampling is adequate to acquire the appropriate information. As expected, visual sampling demands increase as the walking task is made more challenging. When healthy individuals are required to walk in an uncluttered travel path, the demands on the visual system are minimal (average 7 %) [8]. FS was required to walk a shorter distance (about 6.5 m compared to 9 m for the healthy individuals) with a cane in an obstruction free environment. His visual sampling patterns showed a marked increase when compared to the healthy individuals (average 60 %). This suggests greater reliance on vision to maintain dynamic stability and orientation during locomotion.

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