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Predictors of road crossing safety in pedestrians with Parkinson's disease

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ABSTRACT

Road-crossing safety is an important issue in an aging society. Information regarding the risk of crossing the street to pedestrians with Parkinson's disease (PD) is limited. To assess the risk and predictors of unsafe crossing behaviors in patients with PD, we compared 31 pedestrians with mild-to-moderate PD to 50 age/gender/education-matched controls using a battery of cognitive, visual, and motor tests. With a simulated simple street-crossing situation, we determined the remaining time and safety margin for each participant in different traffic situations, including variable motor vehicle speed, time gap, and time of the day. Odds ratios (ORs) were estimated by logistic regression models. We found that pedestrians with PD were more vulnerable to traffic accidents than controls (OR 1.61 [1.28–2.02], $P = 0.01$). The risk of crossing road correlated in a dose-dependent manner with the severity of PD, based on both Hoehn and Yahr (H&Y) stages and unified Parkinson's disease rating scale (UPDRS) motor scores (OR 1.13 for each increasing point of UPDSR, $P < 0.01$). Among PD patients, scores of clock drawing test (OR 0.8 [0.74–0.88], $P < 0.01$) and visual form discrimination (OR 1.14 [1.07–1.22], $P < 0.01$) predicted worsening of safety errors, rather than executive function. Environmental factors, such as fast approaching motor vehicle speed (OR 4.50 [2.92–6.95], $P < 0.01$), short time gap (OR 45.98 [27.04–78.18], $P < 0.01$), and time of day (OR 4.45 [3.11–6.36], $P < 0.01$) also affected road-crossing safety. Future large sample studies are needed to confirm our findings. Training programs or portable stimulator devices that compensate for the visual-spatial disabilities of PD patients are required to improve road safety for PD patients.

1. Introduction

Approximately 1.3 million people die as a result of traffic accidents worldwide each year, ranking it the ninth leading cause of death in this century (Peden and Sminkey, 2004). In the United States, data show that 4378 pedestrians were killed and 69,000 pedestrians were injured in traffic accidents in 2008 (NHTSA, 2008). In contrast to Western countries, where drivers are most at risk of being injured in accidents, pedestrians are the most vulnerable groups of road users in Asian countries (NHTSA, 2008). Safe road crossing requires performance of multiple competing tasks, including visual sensory function, switching the focus of attention between disparate spatial locations, and motor tasks (Owsley et al., 1998). A number of studies have shown that the characteristics of pedestrians, such as old age, and traffic environments are factors that contribute to the risk of pedestrians while crossing the road (NHTSA, 2008; Lobjois and Cavallo, 2007; Oxley et al., 2005; Koepsell et al., 2002). As populations age, the number of patients with neurodegenerative disorders increases exponentially, making road safety an even more important issue (de Lau and Breteler, 2006).

Parkinson's disease (PD) is a progressive neurological disorder predominantly affecting the motor function of patients (Dickson et al., 2009). Detailed pathological examinations of PD patients have shown that neuronal Lewy body deposition not only existed in the substantia nigra, but also multiple cortical regions. In light of the pathological changes in PD and the close connections between the frontal cortex and striatum, PD patients are expected to have deficits in cognitive function (Foltynie et al., 2004). Patients with PD can have executive and visuo-spatial dysfunction (Cooper et al., 1991), poor attention, and deterioration of visual perception (Uc et al., 2005), even in early stages of the disease or drug naïve PD (Cooper et al., 1991; Yu et al., 2012). We hypothesize that these motor and non-motor features could hamper the safety of road-users with PD while crossing the street (Giladi et al., 2001).

Although patients with PD account for more than 1% of the population over 65 years of age and numerous studies have focused on the driving safety of patients with PD (Singh et al., 2007; Uc et al., 2006; Worringham et al., 2006), information regarding the risk

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that pedestrians with PD face when crossing the street is limited. Identifying the risk to pedestrians with PD would be helpful for formulating future training programs or inventing new devices targeting the specific disabilities (e.g., physical or cognitive) of PD pedestrians to improve road safety in this population. Using a simulated simple street-crossing situation, we conducted a case–control study to test the hypothesis that patients with PD have a greater risk when crossing the street than age-matched controls. We also identified the clinical and environmental predictors of unsafe crossing behaviors in PD patients.

2. Materials and methods

2.1. Participants

A total of 81 participants, comprising 31 PD patients and 50 healthy control subjects, matched for age, gender and education level, were included in this study. Informed consent was obtained from each study participant, and the study was approved by the institutional ethics board committee. The subjects were recruited from the neurology outpatient clinics at National Taiwan University Hospital, Yun-Lin branch, and all PD patients fulfilled the diagnostic criteria for PD (Gelb et al., 1999). Each participant underwent a standard neurological examination, including the Mini-Mental Status Exam (MMSE) (Folstein et al., 1975). Patients with PD also underwent a Unified Parkinson's Disease Rating Scale (UPDRS) evaluation (Merello et al., 2011). The inclusion criteria for patients were idiopathic PD with mild to moderate disease severity (Hoehn and Yahr, H&Y, stages I–III) (Hoehn and Yahr, 1967). Exclusion criteria were history of brain surgery, previous exposure of neuroleptic agents, other neurological or psychiatric disorders, MMSE score of less than 24, or impaired visual acuity or hearing ability.

2.2. Visual and cognitive testing battery

All patients with PD were tested during their "on" state. "On" state refers to periods of the day when the PD symptoms are adequately controlled by medication. On the contrary, "off" state refers to periods of the day when the medication is not working well. Participants were allowed to rest as needed.

2.2.1. Basic visual function

All participants had normal visual acuity as defined by the Snellen chart, with at least 20/40 vision, which was expressed as a logarithm of the minimum angle of resolution. All participants also passed the Ishihara color blindness test.

2.2.2. Visual perception

Useful field of view (UFOV) was applied to measure visual perception using the Visual Attention Analyzer (Model 3000, Visual Resources Inc.) (Edwards et al., 2005). UFOV tested three components of visual processing: (1) speed of processing, the subject was asked to identify a central target in the screen, such as a car; (2) divided attention, in addition to identifying the central target as in the previous step, the subject had to identify the radial direction of a target presented at 30° in the periphery; (3) selective attention, the peripheral target of step 2 was embedded in distracters (triangles) and the subject was required to identify it. The UFOV estimate is the total score of three subtests.

2.2.3. Visual-spatial function

We tested visual-constructional abilities using the Rey-Osterreith Complex Figure Test-copy version (CFT-copy) and tested visual memory using the CFT-recall version (Uc et al., 2005). The clock drawing test (CDT) was used to test complex visual-spatial function (Ehreke et al., 2010).

The Benton Visual Form Discrimination (VFD) test is a non-verbal test used to assess the capacity for complex visual form discrimination (Eslinger and Benton, 1983). The VFD test consists of 16 multiple-choice items, and subjects are required to carry out visual searching and complex visual discrimination.

2.2.4. Executive function

The Trail Making Test (TMT) was used to test the executive function of subjects (Reitan, 1955). TMT subtest A (TMT-A), a measure of behavioral regulation and motor speed, requires the subject to connect a sequence of numbers dispersed across a page as quickly as possible without lifting the pen off the paper. The TMT subtest B (TMT-B) requires the subject to connect numbers and letters alternatively. The time spent on TMT-A and TMT-B and the time difference between the two subtests, TMT (B-A), are recorded in seconds and used as an index of cognitive flexibility to switch attention between two competing tasks independent of motor speed.

2.3. Simulated street-crossing experiment

All participants completed a pre-test evaluation to examine their baseline walking behaviors. Walking speed was measured on a 10-m road under normal pace and fast pace conditions. The walking speed was tested under the same condition as in the formal simulated street-crossing experiments. Each subject in either walking pace repeated the testing for 3 times to get the mean value of the walking speed. Each participant completed an 1-h street-crossing experiment comprising three sessions (different vehicle speed, time gap and time of day). Each session was separated by a 10-min rest period to avoid a habituation effect.

2.3.1. Experimental setup

The simulated street-crossing scene was pre-recorded on a real street by a high resolution digital camera (filter diameter: 30 mm; CCD with 690 K effective video pixels) at the height of the eyes of the pedestrians. The pre-recorded rural roadway scene consisted of straight two travel lanes and two bike lanes with relatively few intersections (Fig. 1A). The width of the two-way street was 3.50 m wide between each edge of bike lanes, not including the width of bikes lanes (Fig. 1B). Traffic condition consisted of one car moving at a constant speed from left to right in relation to the pedestrian standing site on the bike lane (Fig. 1B). Given that the sidewalk with edged curb is higher than the roadway by 20 cm in Taiwan, we therefore design the pedestrian standing site is on the bike lane rather than the sidewalk to avoid the confounding effects by the altitude difference. Hence, the pedestrian would directly cross the travel lane without spending time in crossing the curb and bike lane. The midday was recorded at 11:00–13:00, and dusk at 17:50–18:10. The visual scene was projected onto a 17-in. LCD screen, which was 60 cm distance from the participant. The participant's height was also taken into account in order to position the vanishing point at eye level in the images. This setup provided the pedestrian with an up to 50° horizontal and 30° vertical visual field, which is within the central visual field for the normal population (Felsen and Dan, 2005). The image refresh rate was 30 Hz. A press button used to record the participants' responses while they decided to cross the road was connected to a personal computer. Traffic sound effects were broadcast from 2-channel amplifiers.

2.3.2. Experimental procedure

Each participant was seated approximately 60 cm in front of a 17-in. LCD monitor located at eye height with a computer keyboard placed in front of them. Each participant was instructed to place their index finger on the "space" key on the keyboard. The participants subjectively assessed the time they needed to walk 3.5 m. The subjects watched the road scene on a computer screen and decided