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考試日期：0212，節次：1

※ 考生請注意：本試題不可使用計算機。 請於答案卷(卡)作答，於本試題紙上作答者，不予計分。

There are two parts in this exam. PART I is on page one and PART II is on page five. Please read the questions carefully and answer them.

PART I. According to the following research article,

(1) Please write an abstract for this article in Chinese. (30%)

(2) Please discuss the strength and weakness of this study. (20%)

Introduction

Although its analgesic effect is still not completely understood [1], transcutaneous electrical nerve stimulation (TENS) [2,3] is the most widespread analgesic electrotherapy in rehabilitation practice [4,5]. For this reason, clinicians use it by trial and error, believing paresthesias in the affected area to be the best guide for establishing appropriate position and stimulation parameters. In the literature, studies in animals demonstrate that the greatest analgesic effectiveness is achieved when the electrical stimulation is applied to the peripheral nerve fibers afferent to the same spinal cord segment of the sensory fibers supplying the body part in pain [6]. It follows that positioning of the electrodes is considered one of the most determining aspect of the therapy.

To this end, our group recently demonstrated the importance of correct electrode positioning, considering neighboring neurologic territories, to obtain the best pain relief [7]. To make the stimulation more selective and to activate a large number of fibers with small electrical fields, we prefer to use high-frequency transcutaneous peripheral nerve stimulation (HF-TPNS). This is a particular type of TENS characterized by the selective stimulation of a peripheral nerve trunk [7,8].

Little is currently known about possible effects of TENS in body regions distant from the stimulation site. The aim of the study was to investigate the analgesic effect of HF-TPNS in the ipsi- and contralateral skin territory of the stimulated nerve in a group of healthy subjects.

Methods

The protocol used in this study was approved by the Ethics Committee of the "Salvatore Maugeri" Foundation.

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Subjects

Ten healthy, unpaid human volunteers were recruited among the health care employees of our hospital. All the subjects met the following inclusion criteria: (1) at least 18 years of age and (2) right-handed. Exclusion criteria were as follows: (1) a history of peripheral neuropathy, trauma, surgery, or pain in the upper limbs; (2) current or chronic use of medications; (3) previous therapies with TENS; and (4) pregnancy and breastfeeding.

Heat Pain Threshold Measurement

The adopted method was very similar to the one used in previous studies [7,8]. In particular, according to Marstock method [9-12], the heat pain thresholds were measured by Quantitative Sensory Testing using a Peltier contact thermode (12.5-cm^2 surface, 5 × 2.5 cm) connected to a thermal stimulator (MSA Thermal Stimulator, Somedic, Stockholm, Sweden). The thermode was placed on the dorsal hand innervated by the left or right superficial radial nerve (see the protocol).

Subjects were seated in an air-conditioned room (24-26°C) with their upper limbs relaxed while lying on a table with pronated forearms. Elastic straps fixed with Velcro were used to fasten the thermode to the skin.

The thermal thresholds were determined by the method of limits [9,10,13]. Three sets of ascending thermal stimulation were administered to the skin, with temperature increasing 1°C/s from a basal temperature of 32°C. Thermal stimuli were delivered randomly with time intervals from 4 to 10 seconds. Subjects had to press a response switch held in the right hand as soon as the sensation became painful. This switching induced an immediate temperature decrease at 3°C/s. The turning point value represented the subjective threshold (expressed in °C) and the mean of obtained values was considered the heat pain threshold at each evaluation time (see the protocol).

Skin temperature before the beginning of the experiment was at least 28°C.

High Frequency-Transcutaneous Peripheral Nerve Stimulation

Like in the case of heat pain threshold measurement, the method for electrical stimulation was very similar to the one used in previous studies [7,8]. In particular, an electromyograph (Key-Point, Dantec-Medtronic, Skovlunde, Denmark) was used to generate the electrical stimulation (square monophasic waveform, 100 Hz of frequency and 0.1 ms of pulse duration). The stimulation was delivered by 2 disposable, adhesive surface electrodes (28 mm^2, 7 × 4 mm; Alpine Biomed Aps, Skovlunde, Denmark) with the cathode always placed distally. The electrodes were positioned proximally to the left wrist to maximally stimulate the superficial radial nerve along the lateral border of the radius and to evoke a distinct paresthesia in the nerve territory.

After the correct placement of the 2 electrodes, the stimulation intensity was first increased until paresthesia became unpleasant and then lowered until the experienced paresthesia was considered as strong but not unpleasant by the subject. Steps of 1 mA were used to increase and decrease the stimulation intensity. After the last intensity adjustment, the stimulation parameters were no longer modified throughout the experiment.

Protocol

Three different experimental sessions were administered randomly in different days.

In the first session (session 1), 5 measures of the heat pain threshold in the territory of the left radial nerve were performed without any stimulation: the first at baseline (T0), then after 5 (T1), 10 (T2), 15 (T3), and 25 (T4) minutes. In the second and third sessions (session 2 and 3), a left radial nerve electrical stimulation was delivered for 10 minutes immediately after the basal recording (T0). In session 2, heat pain thresholds were measured in the left radial nerve skin territory, whereas in session 3, they were measured in the contralateral corresponding skin area.

Data Analysis

Data are expressed as mean ± standard deviation. Heat pain thresholds measured in the 3 sessions during the 25 minutes of registration were investigated by means of repeated measures analysis of variance (T0 to T4) with one factor (session, 3 levels). In case of significant results (*P* value less than .05 for the interaction between "time" and "session") post hoc tests were performed to identify differences among trends of the different sessions. Differences in heat pain thresholds between baseline and subsequent times also were investigated within each session by means of a repeated measures analysis of variance. All analyses were performed by SPSS statistical software (SPSS, Chicago, IL).

Results

According to inclusion and exclusion criteria 10 subjects (5 male, 5 female, mean age 33.6 years, age range 27-46) were enrolled in the study. Results and statistical significance are summarized in Figure 1, Table 1, Table 2, and Table 3. Means and standard deviations of heat pain thresholds obtained in the 3 sessions at T0, T1, T2, T3, and T4 are illustrated in Table 1. The repeated measures analysis of variance with one factor showed a significant difference (interaction factor) of the heat pain thresholds trend in time (Table 1). The

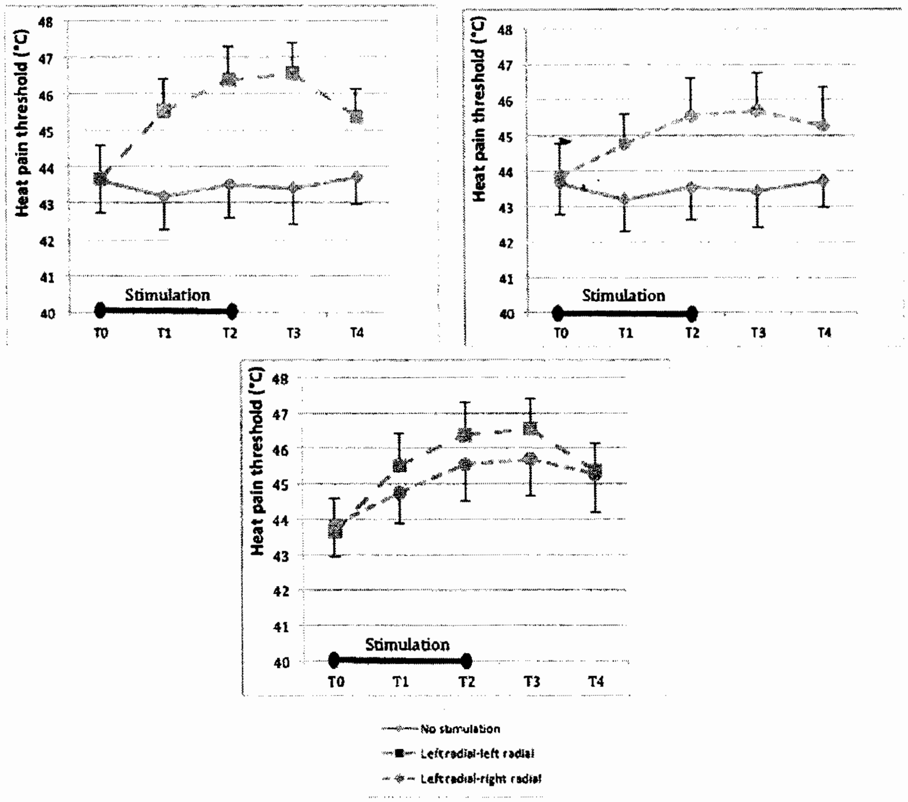

Figure 1. Mean and standard error of heat pain thresholds before during and after the electrical stimulation of the left radial nerve or in absence of any stimulation. The 3 parts of the figure refer to the comparison between the 3 sessions (for further details, see text).

graphic representation of means and standard error of heat pain thresholds in the 3 sessions is shown in Figure 1.

No significant changes in heat pain thresholds throughout the experiment were observed in the session without stimulation (session 1, Table 2). A clear increase of heat pain threshold was observed in the skin territory of the left radial nerve when this nerve was stimulated (session 2, Table 2). It started during electrical stimulation and continued for at least 5 minutes after the stimulation was stopped. From that point, a slow decrease was observed. Although with a lower statistical significance, comparing measures with the basal one (T0), the increase of HPT persisted up to 15 minutes after the stimulation was stopped.

A similar increase of heat pain threshold was also observed in the skin territory of the right radial nerve during and after the left radial nerve stimulation (session 3, Table 2). Statistical analysis confirmed that, when confronted to the basal value (T0), this effect started during the electrical stimulation and lasted 15 minutes after the stimulation interruption.

Considering the differences between each evaluation time and the basal one, in the post hoc test (Table 3), both sessions 2 and 3 were significantly different from session 1 until T4, suggesting a significant analgesic effect for at least 15 minutes after the end of the stimulation. On the contrary, the comparison between session 2 and session 3 never reached the statistical significance, suggesting comparable results in both sessions with stimulation (ipsi- and contralateral to the recordings).

Overall, these results demonstrate that the analgesic effect of the electrical stimulation of the radial nerve

Table 1
Mean and standard deviation of heat pain threshold (expressed in °C) in the 3 sessions

	T0	T1	T2	T3	T4	*P*
Session 1: no stimulation	43.64 ± 2.8	43.18 ± 2.9	43.52 ± 2.9	43.42 ± 3.2	43.72 ± 2.4	<.05
Session 2: left radial-left radial	43.67 ±.29	45.53 ± 2.8	46.38 ± 2.9	46.56 ± 2.7	45.37 ± 2.4	
Session 3: left radial-right radial	43.85 ± 2.9	44.75 ± 2.7	45.55 ± 3.3	45.7 ± 3.3	45.27 ± 3.4	

P refers to the significance of the *interaction* factor (repeated-measures, one-factor analysis of variance: significance level of the interaction term).

T0 heat pain threshold at baseline. T1, T2, T3, T4 HPTs after 5, 10, 15, 25 minutes of stimulation, respectively.

Table 2
Statistical differences (repeated-measures analysis of variance) between heat pain thresholds in each session

	Session 1: No Stimulation	Session 2: Left Radial Stimulation—Left Radial Recordings	Session 3: Left Radial Stimulation—Right Radial Recordings
T1 vs T0	NS	<.005	<.05
T2 vs T0	NS	<.001	<.05
T3 vs T0	NS	<.001	<.05
T4 vs T0	NS	<.01	<.01

NS not significant. T0 heat pain threshold at baseline. T1, T2, T3, T4 heat pain thresholds after 5, 10, 15, 25 minutes of stimulation, respectively.

was greater in its skin territory but a very similar outcome occurred in the contralateral skin area too, with no significant differences between the 2 sides.

Discussion

The most important result of the present study is the evidence of a strong analgesic effect of HF-TPNS in the contralateral side of stimulation. The presence of bilateral effects after unilateral intervention has been pointed out several times in literature, but it is still unclear which mechanisms are involved [14]. To the best of the authors' knowledge, this is the first human study reporting a significant analgesic effect in the contralateral side during and after the ipsilateral stimulation of a peripheral nerve trunk (HF-TPNS). It confirms an animal study in which the subcutaneous electrical stimulation induced both an ipsilateral and a contralateral reduction in spontaneous and evoked activity of nociceptive dorsal horn cells [15]. Interestingly, the present findings suggest the possibility to obtain pain relief when the electrical stimulation is not tolerated in the affected side. Moreover, according to studies in animals [15,16], the present study justifies a bilateral stimulation to try to obtain a stronger pain relief.

The evidence of a strong contralateral effect indicates that part of the analgesic effect of HF-TPNS is mediated by the central nervous system. To this end, the first possible site of interaction between the 2 sides of the body is the spinal cord. The presence of conveying axons between dorsal horns was first described by Ramón y Cajal in 1895 [17]. Another possible connection between the 2 sides of the spinal cord can be found in glial cells activation [18]. In this respect, it is worth noting that the activation of glial cells recently has been considered a mechanism underlying chronic pain [19]. It is also possible that contralateral effects are caused by a mechanisms acting proximally to spinal cord and in particular in brainstem. A unilateral electrical stimulation could indeed activate the endogenous systems of pain modulation located in some brainstem nuclei (periaqueductal grey, raphe nuclei, locus coeruleus) [20,21]. However, in such a case, the effect could be seen well beyond the stimulated segmental level.

Table 3
Comparison between sessions of heat pain thresholds (post hoc test)

	Session 1 vs Session 2	Session 1 vs Session 3	Session 2 vs Session 3
T1 vs T0	<.001	<.01	NS
T2 vs T0	<.001	<.01	NS
T3 vs T0	<.001	<.05	NS
T4 vs T0	<.05	<.05	NS

NS not significant. Session 1 no stimulation; session 2 left radial stimulation-left radial recordings; session 3 left radial stimulation-right radial recordings. T0 = heat pain threshold at baseline. T1, T2, T3, T4 heat pain thresholds after 5, 10, 15, 25 minutes of stimulation, respectively.

The present data differ from those by Dean et al [22], who obtained only an ipsilateral increase of heat pain threshold during and after right median nerve stimulation. This difference may be attributed to the stimulation intensity: whereas in the study by Dean et al the stimulation evoked just a "mild tingling in the hand," in the present experiment it was very strong, although not painful.

Moreover, it is important to underline that our findings confirm previous studies showing the persistence of the analgesic effect of HF-TPNS after the end of the stimulation [7,8,22-24], indicating that continuous stimulation is probably unnecessary. Finally, considering that a reduction of the heat pain threshold is a classical hallmark of inflammation [25,26], the achieved results suggest that HF-TPNS is effective in the treatment of inflammatory painful syndromes.

Conclusions

Although mammals' nervous systems exhibit a high degree of symmetry, transmedian communication is necessary for organism behaviors integration [14]. The results obtained in the present study confirm that contralateral effects of unilateral electrical stimulation exist. Further studies on the possible clinical application of contralateral analgesic effects of TENS are warranted, because they could play a role in treating patients with painful syndromes by physical therapies.

Acknowledgments

We thank the neuropathophysiology technicians Rosa Bagnasco, Michela Canti, and Simona Piazzoli for their indispensable role in data collection and Dr. Paola Baiardi for her considerable help in statistical analysis.

PART II. Below is an article published in 2014, entitled "Effects of dual task on turning ability in stroke survivors and older adults" by Hollands K.L. *et al.* at Gait & Posture 40 (2014): 64–569.

Based on the content of the reading material, please answer the following questions in Chinese with English terminology in parenthesis as needed. (50%)

Q1. According to the authors' description, what problems in turning gait have been found in stroke patients? (10%)

Q2. What are the purposes and hypotheses of this study? (10%)

Q3. Please explain Fig. 1 in the article (page 7) in your own words. (10%)

Q4. What are the main findings of this study? (10%)

Q5. What are the limitations of this study according to the authors' own opinion? (10%)

1. Introduction

The ability to turn while walking, whether to avoid an obstacle or navigate corners, is an integral component of independent mobility. Turning accounts for as many as 45% of steps taken daily [1] and is a risky manoeuvre in which stroke survivors frequently fall [2]. Although falls while turning are more likely to be injurious than during other events [3] and stroke survivors' are at high risk of injury from falling [4], few studies have examined the mechanisms underlying falls during turning following stroke. Those that have [5–7] showed that apart from delayed initiation of turns, longer time to turn and more steps, overall movement patterns were relatively unaffected, even in participants with a history of falls [5]. One clue to a possible mechanism of falling during turning lie in the observation that delayed initiation of turns was alleviated with external visual cues [6]. It was hypothesized that external cues may have served to focus attention on the required turn.

It has been proposed that control of turning may be more cognitively demanding than walking in a straight line [8–10] and that older adults and stroke survivors have limited cognitive capacity [11]. It has therefore been hypothesized [5] that falls during turning after stroke may not be due to an inability to produce movement patterns necessary to achieve a turn but due to cognitive-motor interference [12] (an inappropriate utilization of limited cognitive resources) which causes an exacerbation of motor impairments when additional cognitive demands are made.

1.1. Aims and research questions

The proposed study aims to compare spatio-temporal stepping parameters of healthy older adults and stroke survivors while turning under single and dual task conditions. Stride adjustments have been shown to be an important contributor to the forces driving turning in healthy young adults [13]. As a result we sought

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* Corresponding author at: School of Health Sciences, Room c701, Allerton Building, University of Salford, Salford M5 4WT, UK. Tel.: +44 0161 295 3238.
E-mail address: k.hollands@salford.ac.uk (K.L. Hollands).
URL: http://www.salford.ac.uk

to explore the effects of distraction specifically on stepping patterns as indicators of turning performance.

2. Methods

2.1. Participants

A convenience sample of stroke survivors was identified from community stroke support groups in Greater Manchester and participants of the University's previous studies who agreed to be contacted. We included stroke survivors, irrespective of time since stroke, who had completed their rehabilitation and were able to walk 10 m and turn without assistance from walking aids or another person. Participants were excluded if they had language problems which prevented reliable participation in the spoken subtraction task.

Age-matched healthy volunteers aged over 50 years (the older adult group) were recruited from University staff and participants of previous studies. Exclusion criteria for both stroke and older-adult groups were any condition (apart from stroke) that limited mobility. The study was approved by the University Ethics Committee and all participants provided written informed consent.

2.2. Sample size calculation

A sample size calculation based on data from the first four stroke survivors indicated that a sample of 15 would detect differences in single support duration while turning under single and dual task conditions ($p < 0.05$, power = 0.950). Single support time was chosen as the basis for the power calculation as it is related to turning capacity following stroke [7].

2.3. Procedures

Participants walked along a (3.7 m) pressure sensitive mat (GAITRite) and turned 90 to exit the mat to either the left or right. Start and end points were marked on the floor with tape 1 m from either end of the mat (to exclude acceleration and deceleration phases on the mat) and to mark the turning point to exit walkway (see Fig. 1A). As participants walked along the GAITRite, pressure sensors are activated during stance and deactivated during swing phase of each limb, providing spatial and temporal parameters of walking with demonstrated validity and reliability [14]. Participants walked and turned (under single task conditions) and while subtracting serial 3's from a random number in the 100 s, aloud (dual task condition). This dual task was chosen because we sought a task that was sufficiently challenging to show differences in turning under distractions to attention [11], should they exist and verbal subtraction has been shown [15] to interrupt gait more than other cognitive tasks.

Six trials under each condition (single or dual task) and turning to each direction (to the paretic or non-paretic side) were performed; 24 walking trials in total. The order of trials was randomized to balance and minimize effects of learning and fatigue. Participants walked at their self-selected pace with rest breaks as needed and after every 6 trials.

2.4. Measures

Gait speed, step length, stride time and stride time variability were taken during the straight portion of the walking trial [16]. These measures were selected because of their known sensitivity to dual-task interference after stroke [17]. Specifically, low stride-to-stride variability reflects automatic processes that require minimal attention and is associated with efficient gait control and gait safety [18]. As participants may use a different number of steps to achieve a turn, mean and standard deviations of spatial and temporal parameters were compared on a step by step basis over the last 2–3 steps before the participant left the mat. These turning steps were identified as Step 1 (penultimate) and Step 3 (ultimate) steps of the foot ipsilateral to the turn (Fig. 1A). Step 2 was the last step of the foot contralateral to the turn.

Gait parameters were calculated by GAITRite software including step width, step length (relative to line of progression in accordance with recommendations on measuring spatial stepping parameters in non-linear walking) [19] (Fig. 1A) and single support time. Time taken to turn was calculated as the difference (in time) between initial contact of Step 1 and the last contact of Step 3 (if registered) or Step 2 (if step 3 was already clear of the walkway). Variability of time to turn was calculated as the standard deviation, across trials, of the time to turn.

Mean values of step parameters were only taken when data for a given step was present for a minimum of three trials in each condition. Therefore, if participants had already exited the walkway by Step 3 on more than three trials (i.e. they carried out the turn in two steps) then data for Step 3 would not be available for analysis.

Performance on the cognitive task was measured as the number of correct responses (normalized to the time taken) while completing the walk and turn. The scores on the serial subtraction task were normalized as those taking longer to walk and turn would have more time to provide answers during serial subtraction.

Measures to describe the stroke participants' impairment and activity limitations were also taken: The Dual Task Telephone Search (sustained attention) and Elevator counting with distraction (attentional switching) subtests from the Test of Everyday Attention (TEA) [20] assessed attentional abilities; the Timed Up and Go (TUG) [21] assessed mobility and the Berg Balance Scale (BBS) [22] assessed balance.

2.5. Statistical analyses

Mixed analysis of variance for repeated measures was used to determine differences in spatial and temporal gait measures separately for the straight walking portion of the trial and during each of the 3 turning steps. The 'between subject factor' was group (stroke vs. older-adults) and the 'within subject factors' were: task condition (single vs. dual task) and direction of turn (to the paretic vs. non-paretic side). The within subject factor of direction was not used for straight walking analyses. For purposes of comparison, the left side was assigned as paretic for older-adults. A p value of <0.05 was used for statistical significance. If the overall F test was significant, inspection of means were used to identify where significant difference(s) lay. The software package SPSS (version 20) was used.

3. Results

3.1. Participants

Seventeen stroke survivors participated; the group had a mean (± SD) age of 64 (±10) years and a mean time since stroke of 59 months (±113), three were female and 6 right hemiplegic. Further details are found in Table 1.

Using the walking speed thresholds described in the Walking Handicap Scale [23], four participants were not functional walkers (in everyday life) (speed <0.4 ms), six were mobile indoors (walking speed 0.4–0.6 m/s) and five were limited outdoor walkers (speed = 0.6–0.8 m/s). None had unlimited outdoor mobility (>0.8 m/s). Using 14 s as the threshold to indicate a high risk of falls on the TUG test [24], four participants had a high risk of falls, two of whom reported falling in the last year. None of the stroke survivors scored less than 45 on the BBS, which is a proposed threshold [25] of increased falls risk post-stroke. Five stroke survivors had 'abnormal' scores (<5th percentile of normative scores) on subtests of the Test of Everyday Attention (TEA). Six participants were unable to perform one or both of the TEA tests as they were without reading glasses or had hearing impairments.

The fifteen healthy older-adults participants had a mean age of 68.5 (range 55–82) years, mean self-selected walking speed of 0.65 m/s (range 0.48–0.77) and TUG time of 10.05 s (range = 7.14–14.66 s). All lived independently in the community and none reported falling in the past year.

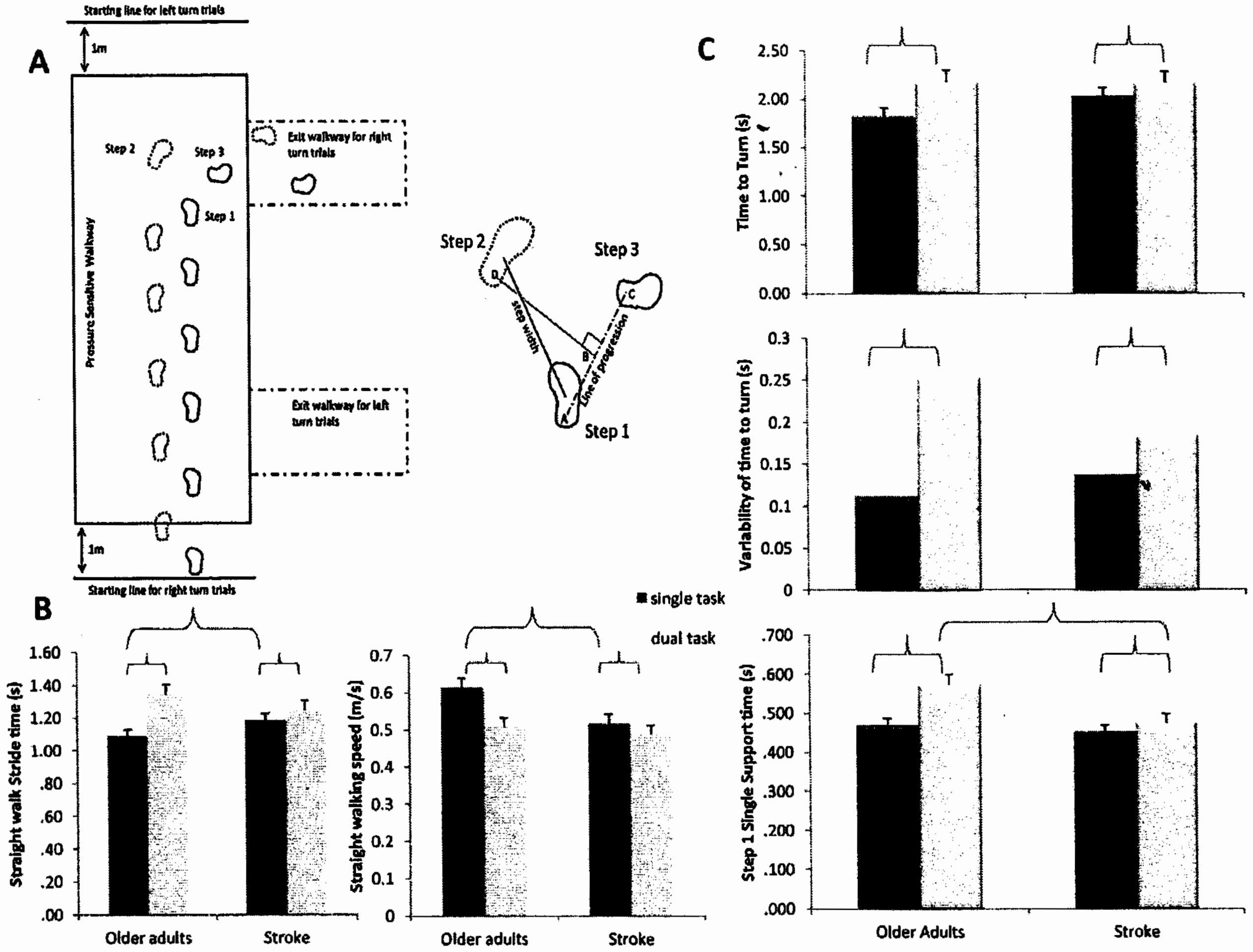

Fig. 1. (A) Schematic of methods. Paretic/left footprints are depicted with dashed outlines and non-paretic with solid outlines. Exit walkways and starting lines are delineated by tape on the floor. Line AC is the line of progression from heel centre of two consecutive footfalls of the same foot. Line segment DB is perpendicular to the line of progression. Line segment AB is step length of step 2 and line segment BC is step length of step 3. Step width is from midpoint of current footprint to midpoint of previous footprint on the opposite foot. To avoid computational mistakes, step length and width were calculated as the distances between successive footfalls relative to the change in direction at each stride in accordance with recommendations by Huxham et al. [19]. (B) Effects of dual task on straight walking. Bottom left panel shows stride time (s) and walking speed (m/s) during straight walking in older adults and stroke survivors. Single task conditions are shown in dark filled bars and dual task in lightly filled bars. Error bars represent standard error. Significant differences are denoted by parentheses. (C) Effects of dual task on turning. Upper most panel illustrates time taken to turn (s). Bars represent mean turn time (s). The middle panel illustrates mean variability of time to turn (s). Lower right panel illustrates mean single support phase (s) during step 1 of the turn. Bars are for older adults and stroke, during single task (dark grey) and dual task conditions (light grey). Error bars represent standard error. Significant differences are denoted by parentheses.

3.2. Engagement with the dual task

There were no statistical differences in the number of correct responses during serial subtraction between older-adults and stroke survivors (mean (SD) = 0.76 (0.23) and 0.63 (0.30) correct responses per second, respectively). Similarly, there were no statistical differences in performance on the cognitive task according to the direction of the turn (to the paretic or non-paretic side).

3.3. Effects of dual task on straight walking (Fig. 1B)

A main effect of task was found indicating speed was slower under dual task conditions than single task ($p < 0.001$, $F(1,27) = 43.52$). A significant interaction between task and group ($p < 0.001$, $F(1,27) = 13.04$) indicated stroke survivors walked slower than older-adults under single task conditions but showed no difference between groups under dual task conditions (see Fig. 1B). A main effect of task on stride time indicated stride time increased ($p < 0.001$, $F(1,27) = 36.00$) under dual task conditions. A significant interaction effect between task and group ($p < 0.001$, $F(1,27) = 14.29$) indicated that older-adults have shorter stride time in single task conditions than stroke survivors and in comparison to dual task conditions (see Fig. 1B). A main effect of task on variability of stride time indicates variability greater ($p = 0.013$, $F(1,27) = 6.99$) under dual than single task conditions for both stroke survivors and older-adults (mean (SD) = 0.105 s (0.068) and 0.067 s (0.063) respectively).

3.4. Stepping patterns while turning under single task conditions

Details of values for each parameter and the comparisons between stroke survivors and older-adults, single and dual tasks while turning are shown in Table 2. There was no difference in the time to turn between older-adults and stroke survivors but a main effect of turn direction indicated turns to the non-paretic side took longer (mean = 2.08 s (SD 0.43)) than the paretic (2.02 s (0.42); $p = 0.029$, $F(1,27) = 5.32$) in both groups. Variability of time to turn showed no differences between groups or directions of turn. Stroke survivors used shorter, narrower steps at steps 1 and 2 during the turn and had shorter single support time than older-adults (see Table 2).

3.5. Stepping patterns while turning under dual task compared to single task conditions (Table 2 and Fig. 1C)

The data for comparisons of turning under single and dual tasks conditions are detailed in Table 2. Main effects of task indicate both stroke survivors and older-adults turned more slowly under dual than single task conditions ($p = 0.013$, $F(1,27) = 7.42$). Variability of time to turn was higher during dual than single task conditions for both groups ($p = 0.043$, $F(1,27) = 4.53$).

There were no significant differences in step length or width at steps 1 and 3 of the turn between single and dual task conditions, but there was a trend for step 2 to be wider under dual task conditions (see Table 2). Single support phase was longer

Table 1

Participant information. SSWS, mean self-selected walking speed; BBS, Berg Balance Scale; TUG, Timed Up & Go test; M, male; F, female. Scores for the TEA are the mean score and corresponding percentiles for the participants' age group. TEA scores with an * are those classified as abnormal, i.e. below the 5th percentile.

Participant	Gender	Age (years)	Time since stroke (months)	Paretic side	SSWS (m/s)	TUG (s)	BBS	TEA – sustained attention Elevator with distraction	TEA – divide attention ability Telephone with distraction	Falls
01	M	71	24	Left	0.31	16.3	49	Unable to complete; hearing impairment		0
02	M	50	32	Left	0.61	7.7	56	7 (12.2–20.2%)	6 (6.7–12.2%)	0
03	M	65	13	Left	0.66	10.1	53	5 (3.3–6.7%)*	9 (30.9–43.3%)	0
04	M	79	22	Left	0.38	15.4	53	7 (12.2–20.2%)	12 (69.2–79.8%)	2
05	M	53	17	Right	0.58	9.6	56	8 (20.2–30.9%)	7 (12.2–20.2%)	0
06	M	69	3	Left	0.49	11.4	56	6 (6.7–12.2%)	7 (12.2–20.2%)	0
07	F	65	12	Left	0.4	8.5	56	5 (3.3–6.7%)*	Unable to complete; no reading glasses	0
08	M	59	96	Right	0.53	12.6	49	Unable to complete; hearing impairment		0
09	M	59	16	Left	0.67	8.2	53	8 (20.2–30.9%)	14 (87.8–93.3%)	0
10	M	60	21	Left	0.38	9.94	55	Unable to complete; hearing impairment		0
11	F	79	24	Left	0.64	10.6	52	11 (56.6–69.2%)	5 (3.3–6.7%)*	0
12	M	78	12	Right	0.44	10.3	55	11 (56.6–69.2%)	Unable to complete; no reading glasses	0
13	F	51	127	Left	0.48	12	52	7 (12.2–20.2%)	8 (20.2–30.9%)	0
14	M	71	11	Left	0.66	8.7	56	6 (6.7–12.2%)	10 (43.4–56.6%)	0
15	M	61	34	Right	0.44	16	48	6 (6.7–12.2%)	3 (0.6–1.5%)*	0
16	M	52	65	Left	0.23	19.5	52	Unable to complete; hearing impairment		1
17	M	66	480	Right	0.52	11.9	52	3 (6.7–12.2%)*	5 (3.3–6.7%)*	1
Means (SD)	3 female	64 (9.6)	59.4 (113.3)	6 right	0.49 (0.13)	11.7 (3.3)	53.1 (2.6)	7 (2.1) [12–20%]	8 (3.2) [20.2–30.9%]	3 fallers

during dual than single task conditions for both stroke survivors and older-adults ($p = 0.001$, $F(1,29) = 13.08$), and older-adults had a longer single stance phase than stroke survivors under dual task conditions (Fig. 1C).

4. Discussion

The aim of this study was to determine the effects of increased cognitive demands on stepping patterns while turning in stroke survivors and age-matched healthy older-adults. We sought to explore the effects of cognitive-motor interference on the stepping patterns of turning in order to identify possible biomechanical mechanisms for falls while turning. We hypothesized that stroke-related movement impairments during turning may be induced or exacerbated by ineffective utilization of cognitive resources (distraction). Overall, our findings support this hypothesis. Results indicate both groups took longer, were more variable, tended to widen the second step and, crucially, increased single support time on the leg ipsilateral to the turn when distracted. These findings confirm the idea that control of turning requires cognitive resources [8,9] and importantly identifies changes to stepping patterns which may underlie increased falls risk during turning in older-adults and stroke survivors.

In contrast to improved stability when gait speed is reduced in response to distraction during straight walking [11], the result of slower turning is that longer is spent in single support phase. As one turns, the swing leg on the outside of the turn (step 2) must travel further around the arc of the turn than the stance leg (step 1) on the inside of the curve [13]. The slower the turn, the longer it will take the swinging leg to complete the arc of the turn (unless a greater number of steps are taken within the turn). Consequently single support time on the contra-lateral/inside limb (step 1) is increased. Single support is an inherently unstable phase of gait as the base of support is at its smallest and longer time in this phase is correlated with increased trunk leaning to the inside of the turn [13]. Thus our finding that both stroke survivors and older-adults tend to spend longer in single stance while turning under cognitively demanding conditions is a likely contributor to the high incidence of falls observed during this activity. Further, these findings corroborate previous suggestions that turning ability is linked to single support duration in stroke survivors [7].

Turning may be particularly challenging for stroke patients due to the fact that the manoeuvre imposes step asymmetries on an already asymmetric walking pattern and hence turns to a particular direction may be more difficult depending on the side of underlying asymmetry. However, our results show few differences in stepping patterns according to turn direction; a finding that has also been reported in previous studies [5–7]. Given that the direction and extent of step asymmetry has been shown to vary according to age, motor recovery level and walking speed [26–28], systematic differences in stepping patterns according to the direction of the turn may be obscured by the complexity of relationships between these variables.

This is the first report of turning under dual task conditions and so opportunities for like-for-like comparisons with other studies are limited. However, there are similarities with reports of other aspects of the effects of cognitive demands on walking and turning

Table 2
Summary of turning performance between groups and task conditions. Means, standard deviations and statistics are reported for main effect comparisons between groups and task conditions. Significant interaction effects between task and group were only found for single support duration and this is discussed within the text with means presented in Fig. 1C.

		OA	Stroke	Comparison between stroke survivors and older adults	Dual task condition	Single task condition	Comparison between single and dual task conditions
Mean time to turn (SD) (s)		1.99 (0.39)	2.12 (0.45)	No significant difference	2.2 (0.46)	1.92 (0.34)	$p < 0.001$, $F(1,27) = 33.72$
Mean variability of time to turn (SD) (s)		0.18 (0.09)	0.16 (0.08)	No significant difference	0.22 (0.10)	0.12 (0.06)	$p < 0.001$, $F(1,27) = 18.84$
Step 1 Means (SD)	Step-width (cm)	69.65 (8.53)	56.44 (11.08)	$p = 0.001$, $F(1,29) = 14.48$	62.61 (9.41)	63.48 (10.36)	No significant difference
	Step-length (cm)	64.75 (14.19)	54.85 (13.57)	$p = 0.001$, $F(1,29) = 13.96$	60.26 (12.63)	61.43 (12.03)	No significant difference
	Single support (s)	0.52 (0.12)	0.46 (0.09)	$p = 0.046$, $F(1,29) = 4.36$	0.52 (0.10)	0.46 (0.07)	$p < 0.001$, $F(1,29) = 30.73$
Step 2 Means (SD)	Step-width (cm)	61.73 (13.69)	54.56 (10.75)	$p = 0.007$, $F(1,29) = 8.43$	58.87 (13.11)	56.66 (12.37)	$p = 0.51$, $F(1,29) = 4.13$
	Step-length (cm)	59.48 (13.99)	52.42 (11.29)	$p = 0.005$, $F(1,29) = 9.39$	57.24 (11.69)	56.04 (10.91)	No significant difference
Step 3 Means (SD)	Step-width (cm)	51.81 (13.35)	46.01 (11.06)	No significant difference	50.07 (9.81)	49.4 (12.53)	No significant difference
	Step-length (cm)	42.64 (20.79)	31.76 (17.67)	No significant difference	39.6 (14.1)	38.3 (19.58)	No significant difference

after stroke, that support the validity of our findings. Although our participants tended to walk more slowly [5–7] the movement patterns described while turning under single task conditions are similar, stroke survivors used wider, shorter steps than age-matched counterparts but demonstrated similar speed and variability [5–7].

Further, our results of the effect of dual-task conditions on straight walking (increased stride time and variability in both groups) are also in-line with previous reports [16]. Given that dual-task conditions are known to degrade walking performance even in healthy elderly [11,15] and that turning is a major contributor to falls in the elderly [29], it is not surprising that older-adults also show difficulties in dual-task turning. It has been suggested that cognitive and motor conflicts are greater with more complex locomotor tasks and/or if the gait pattern is already impaired [10,15] so it may be that the dual-task turning was challenging for both groups. Indeed, fewer stroke survivors showed evidence of impaired attention than previously reported [30] and it may be that older adults had undetected cognitive/mobility deficits equalizing dual-task decrements across groups in this study.

5. Limitations

Like most dual-task studies [16], this study is limited in ecological validity as testing was conducted in a controlled environment and we do not know how the movement patterns measured under such conditions relate to 'real life'. It is possible that the impact of dual tasks on turning might be even greater in a community environment. Further, participants of this study were relatively high functioning; as they needed to be sufficiently mobile to take part in the protocol, and so findings may not be generalizeable to those with even more severe limitations. But, again, one would predict that the impact of dual tasks on turning in more severely limited participants could be even greater.

We have taken a cross-sectional approach to the investigation; more research is needed to investigate how movement patterns during turning may be associated with falls incidence/risk, and how turning ability changes over the course of recovery following stroke and with increasing frailty in ageing. It may be that stroke survivors and older-adults who recover/maintain unlimited community ambulation would not exhibit the same dual task decrements to turning as we have seen here. It remains to be seen if less risky compensatory strategies for turning could be identified and taught, or if dual task training can be effective either by way of increasing automaticity of the motor task, or improving the capacity of cognitive resources (or both).

6. Conclusions

Importantly, this is the first study to identify a vulnerability to falling in the biomechanics of turning in healthy older-adults and following stroke. Surprisingly, we found that stroke survivors and older-adults demonstrated similar dual task decrements to turning. These findings highlight the importance of considering the interaction between cognitive processes and walking in the research and treatment of all populations at risk of falling. Further, research and treatment should extend to advanced gait skills, such as turning, which are necessary for safe independent community ambulation.

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