A Preliminary Study of Dual-Task Training Using Virtual Reality: Influence on Walking and Balance in Chronic Poststroke Survivors

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Background: Stroke is a leading cause of death and disability in the Western world, and leads to impaired balance and mobility. *Objective*: To investigate the feasibility of using a Virtual Reality-based dual task of an upper extremity while treadmill walking, to improve gait and functional balance performance of chronic poststroke survivors. *Methods:* Twenty-two individuals chronic poststroke participated in the study, and were divided into 2 groups (each group performing an 8-session exercise program): 11 participated in dual-task walking (DTW), and the other 11 participated in single-task treadmill walking (TMW). The study was a randomized controlled trial, with assessors blinded to the participants' allocated group. Measurements were conducted at pretest, post-test, and follow-up. Outcome measures included: the 10-m walking test (10 mW), Timed Up and Go (TUG), the Functional Reach Test (FRT), the Lateral Reach Test Left/Right (LRT-L/R); the Activities-specific Balance Confidence (ABC) scale, and the Berg Balance Scale(BBS). *Results:* Improvements were observed in balance variables: BBS, FRT, LRT-L/R, ($P < .01$) favoring the DTW group; in gait variables: 10 mW time, also favoring the DTW group ($P < .05$); and the ABC scale ($P < .01$). No changes for interaction were observed in the TUG. *Conclusions:* The results of this study demonstrate the potential of VR-based DTW to improve walking and balance in people after stroke; thus, it is suggested to combine training sessions that require the performance of multiple tasks at the same time.

Key Words: Disability—exercise—gait—treadmill—training

Introduction

Stroke is one of the main causes of death and disability in the Western world.[1] Stroke survivors often exhibit deficits in motor control, which contribute to reduced balance and mobility.[2,3] Although the majority of persons after stroke recover at least some of their walking capability following rehabilitation, balance and walking deficits persist throughout the chronic stage.[4] Reduced static and dynamic postural control causes a major risk of falling,[5,6] and limits the ability to perform daily activities.[7] Consequently, researchers and therapists have been seeking ways to improve the participation of persons after stroke in community activities through training that increases their balance control and self-confidence in walking.[1,8-10] Over the past 20 years, a variety of intervention approaches have been developed for improving postural control while walking, including functional training, walking on a treadmill, strength training, and balance training.[4] One of the preferred walking retraining methods is treadmill training, which is a whole-task practice that controls the incline and speed, and has been shown to improve walking ability in poststroke survivors.[11-13] However, this approach is designed only to facilitate single-task performance in walking, while community walking is typically a multitask activity where individuals

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often perform a number of tasks simultaneously, such as talking to a friend, using a mobile phone, carrying a bag, or observing traffic while walking.

Therefore, some researchers have suggested that dual-task training may improve balance and walking among stroke survivors.[14,15] Dual-task training while walking has been implemented in the group activity of poststroke survivors, where they walk on a level surface while holding 1 or 2 balls, raise an umbrella using both hands, or bounce a basketball.[15] Other researchers studied dual tasking that included walking on a treadmill while performing cognitive tasks.[16] Researchers have also implemented dual-tasking while walking on a treadmill and using specifically designed virtual reality (VR) environments, demonstrating tracking tasks of walking down the street, and encountering virtual obstacles.[17,18] In these studies, participants who were poststroke survivors demonstrated improvement in balance and other walking variables. Another specifically designed VR environment was presented by Kizony et al,[19] who used a VR context of walking in a store and choosing items from the shelves. The common VR contexts used in this kind of research enabled anticipatory mobility control toward visual stimuli. So far, however, no study has included an intervention in which the participants use VR while walking on a treadmill and are asked to react with their upper limbs toward unexpected stimuli, thereby mobilizing complex control reactions that include both anticipatory and reactive control. Therefore, the purpose of the current study was to investigate the feasibility of using VR-based dual-task training of upper-extremity tracking while treadmill walking, to improve walking and balance performance in poststroke survivors.

Patients and Methods

Participants

Twenty-two persons (17 males, 5 females) with chronic poststroke (hemiplegia) conditions, who attend a community physical activity program, were randomly assigned into 2 groups: an experimental group (n = 11, mean age 66 ± 8.6 years) and a control group (n = 11, mean age 64.4 ± 9.4 years). Participants were required to take out one of 22 notes from a bag—half were marked with a line and other half were not marked at all. Then each note was crumpled into a small ball so that it was impossible to see if the note had been marked with a line, and finally the notes were inserted into the bag. The examiner could not know which note the participant was taking out, and the participants didn't know that there was an experimental and control group or what the notes represented. Participants were recruited from 2 community rehabilitation centers for persons with disability. The same trainer conducted the training in both centers. Assessors were blinded regarding group allocation.

Inclusion criteria were: (1) hemiplegia after a stroke for at least 1 year since the incident; (2) age range 40-80 years old; (3) not taking medication or with unchanged medication throughout the past half year or longer; (4) using an ankle-foot orthosis or having no splint at all; (5) and can do a regular walk of 10 m without and with single point stick. Exclusion criteria were: (1) major cardiac problems; (2) a score of less than 25 in the Mini-Mental test; (3) fractures or severe orthopedic limitations that do not allow for training, and which occurred over the last 6 months; and (4) more than 3 falls in the year prior to participating in the study.

The study was approved by the Loewenstein Rehabilitation Hospital Institutional Review Board (001-13-LOE). Prior to participating in the study, each participant signed a consent form that was in accordance with the Helsinki declaration.

Study Design

Randomized controlled trial with assessors' blinded regarding group allocation.

Intervention

The intervention of the experimental group was based on dual-task treadmill walking while using a VR tool. The participants in the control group performed a single-task treadmill-walking exercise routine.

VR Instrumentation

The SeeMe system (Brontes Processing: Gliwice, Poland)—a projected video-capture VR system that works with a standard PC and a single, standard web video camera—was used in the study. Participants were positioned on the treadmill in a demarcated area in front of a large television screen.

Dual-Task Walking (DTW)

Each training session began with 8 minutes of warm-up that included mobilization and flexibility exercises and a 2-minute walk around the gym. Then, for safety reasons, the participants were attached to a harness. The participants began to walk slowly on the treadmill and continued for 3 minutes. In the phases that followed, the participants walked at the same speed while training with 3 VR games: (1) the ball game—participants were required to strike the virtual balls with their upper extremity, approaching them from different targets. In later stages of the game distractions were added, such as virtual shoes approaching randomly from different directions, which had to be avoided; (2) reactive boxing—virtual boxes appeared randomly and at fixed distances on both sides of the screen. The participant needed to touch the virtual box within a specified period of time; (3) cleaning windows—the participants were required to clean a series of windows as quickly as possible by wiping off the virtual dirt that covered the window. Each session

lasted 3 minutes and was followed by 3 minutes of single-task walking separating the VR sessions. After the final VR session, 2 minutes of single-task walking was performed in order to allow for recovery. The total time walked in each trial was always 20 minutes.

The intervention in the control group was based on single-task treadmill walking (TMW).

Single-Task Treadmill Walking (TMW)

In this intervention, participants performed the same warm-up routine as in the DTW, including mobilization, flexibility, and walking around the gym, and then continued to walk for another 20 minutes on the treadmill at a speed that was equivalent to the intensity of 60%-70% of their heart rate reserve (calculated by the Karvonen method).

Procedure

Trained practitioners blinded to the participants' allocated group assessed the outcome measures throughout the testing schedule. Participants underwent 3 testing sessions and 1 intervention period, as follows: Preintervention test—performed 1 week prior to the intervention period; Intervention period—the interventions included 8 treatment sessions carried out twice per week for 4 weeks; Postintervention test—performed on the day after the end of the intervention period; Follow-up test—performed 4 weeks after the end of the intervention period.

Outcome Measures: (1) the over-ground 10-m walking test (10 mW m/s)[20]; (2) the number of steps completed by the participants during the 10-m walk (10 mW-Steps)[20]; (3) Timed Up and Go[21]; (4) the Functional Reach Test (FRT)[22]; (5) the Lateral Reach Test—the participant is asked to reach as far as possible to the right (LRT-R) and to the left (LRT-L) sides[23]; (6) activity-specific Balance Confidence (ABC)[24]; (7) the Berg Balance Scale (BBS).[25]

Statistical Analysis

In order to examine the possibility of differences in the clinical and demographic characteristics of the participants between the 2 groups, an independent *t* test (for interval-scaled variables) and a chi-square test (for ordinal-scaled variables) were conducted prior to the intervention.

The effect of the intervention program in the experimental group compared to the control group was examined by using a 2-way ANOVA with repeated measures: 2 groups (control and experimental) and 3 test times (pre, post, follow-up). A correction for multiple comparisons was done by using false recovery method.[26]. Partial Eta^2 was used to measure effect sizes for ANOVA. The scales of magnitude for partial eta squared [η_p^2] recommended by Cohen is small less than .02; medium = .02-.25; and large greater than .25. Statistical significance was set at P less than .05. The statistical analysis was performed using the IBM SPSS Statistics 21.

Results

The demographical and clinical parameters of the participants are presented in Table 1. As can be seen, there were no statistical differences between the control and experimental groups in any of the variables measured.

The motor outcome measurements at the pretest (baseline) are presented in Table 2. As can be seen, there were no statistical differences between the control and experimental groups in any of the variables measured.

The adherence to the intervention was 100% for both groups, and there was no dropout during the study.

The outcomes measured throughout the 3 assessment periods across the experimental and control groups are presented in Figures 1 and 2. The results presented in Figure 1 indicate the differences obtained in actual walking variables and in walking confidence: (1) a significant interaction with medium ES favoring the intervention group was demonstrated between groups and time in 10 mW m/s ($F = 3.43$; $P = .04$; $\eta_p^2 = .15$). Posthoc pairwise comparisons across group revealed significant differences between the pre- and postperiods in the experimental group (FDR critical $P = .037$); (2) a significant interaction with medium ES favoring the intervention group was demonstrated between groups and time in number of steps completed during the 10 mW steps ($F = 3.49$; $P = .04$; $\eta_p^2 = .15$). Posthoc pairwise comparisons across group revealed significant differences between the pre- and postperiods in the experimental group (FDR critical $P = .031$); (3) no significant interaction with medium ES was found across groups and time in the Timed Up and Go test ($F = 1.53$; $P = .23$; $\eta_p^2 = .07$). Posthoc pairwise comparisons across group revealed significant differences between the pre- and postperiods in the experimental group (FDR critical $P = .05$); (4) a significant interaction with large ES across groups and time favoring the intervention group was demonstrated in ABC ($F = 9.0$; $P = .001$; $\eta_p^2 = .31$). This interaction occurred due to a reduction in balance confidence of the control group and an increase in the intervention group. Posthoc pairwise comparisons across group revealed significant differences between the pre- and postperiods in the experimental group (FDR critical $P = .025$).

The results presented in Figure 2 demonstrate the differences obtained in the balance variables: (1) a significant interaction with large ES across groups and time favoring the intervention group was demonstrated in BBS ($F = 21.46$; $P = .001$; $\eta_p^2 = .52$). Posthoc pairwise comparisons across group revealed significant differences between the pretest and both of the other measuring times in the experimental group (FDR critical $P = .018$); (2) a significant interaction with large ES across groups and time favoring the intervention group was demonstrated in FRT

Table 1. *Demographic and clinical measurements at baseline for both groups*

Clinical and demographic quantitative data	TMW group	DTW group	*T* test	Chi-square
Average age (y)	66	64.36	.661	
Average time after stroke (y)	9.55	8.57	.315	
Average range of elbow movement in extension	95	126.36	.896	
Average range of shoulder movement in extension	80.45	119.55	.377	
Clinical and demographic qualitative data				
Gender (male/female)	7 males, 4 females	10 males, 1 female		.127
Side of the stroke (right/left)	8 right side, 3 left side	5 right side, 6 left side		.193
Muscle strength (0-5) of quadriceps in extension	Strength 2-1 participant, strength 3-8 participants, strength 4-1 participant, strength 5-1 participant	Strength 1-1 participant, strength 2-2 participants, strength 3-2 participants, strength 4-5 participants, strength 5-1 participant		.107

Table 2. *Descriptive baseline motor measurements at for both groups*

Variable	DTW group	TMW group	*T* test	*P*
	Mean (SD)	Mean (SD)		
10 mW time (s)	17.85 (8.38)	24.69 (16.26)	1.24	.229
10 mW (number of steps)	23.94 (5.37)	26.21 (8.14)	.74	.471
TUG (s)	21.53 (11.01)	23.67 (21.18)	.30	.770
FRT (cm)	20.64 (7.01)	21.05 (7.17)	.14	.894
LRT-L (cm)	12.36 (7.27)	11.45 (13.66)	.20	.847
LRT-R (cm)	12.41 (9.10)	14.18 (10.08)	.43	.670
BBS (score)	40.55 (6.04)	43.18 (10.02)	.75	.463

($F = 7.26$; $P = .001$; $\eta_p^2 = .27$). Posthoc pairwise comparisons across group revealed significant differences between the pretest and both of the other measuring times in the experimental group (FDR critical $P = .006$); (3) a significant interaction with large ES across groups and time favoring the intervention group was demonstrated in LRT-L ($F = 14.75$; $P = .001$; $\eta_p^2 = .42$). Posthoc pairwise comparisons across group revealed significant differences between the pretest and both of the other measuring times in the experimental group (FDR critical $P = .012$); (4) a significant interaction with large ES across groups and time favoring the intervention group was demonstrated in LRT-R ($F = 7.23$; $P = .001$; $\eta_p^2 = .27$). Posthoc pairwise comparisons across group revealed significant differences between the pre- and post-periods in the experimental group (FDR critical $P = .043$).

Discussion

This study presents the potential of using an off-the-shelf, low-cost VR system for applying dual-task performance conditions during walking, in persons who have suffered a stroke. The outcomes of the study indicate a significant advantage of DTW as compared to the TMW in improving walking and balance in this population. More specifically, the results of the study indicated a significant increase in walking speed and length of steps of participants in the DTW group following the intervention, compared to no change among participants in the control group following the TMW intervention. Our findings may be supported by outcomes in the study of search. Yang et al,[27] who found improvement in walking speed after 12 sessions of actual dual-task training (walking while carrying a tray holding drinking glasses or walking and pressing buttons at the same time). These researchers suggested that the improvement in walking performance under dual-task conditions may imply an improvement in walking functions in the community. Our findings are also supported by the results of a study by Cho and Lee,[18] which had a similar design to the current study and demonstrated a significant interaction between the experimental group and the control group in walking speed and the number of steps after 18 sessions of walking training on a treadmill with a VR system. However, in contrast to our VR modality, in their study the VR scenes displayed various simulated scenarios, such as a wet path, crosswalks, night walks, and walking among other people; however, there were no tasks specifically with the upper extremities. Also different from our study was their control group, which practiced walking on a regular track without a VR system.

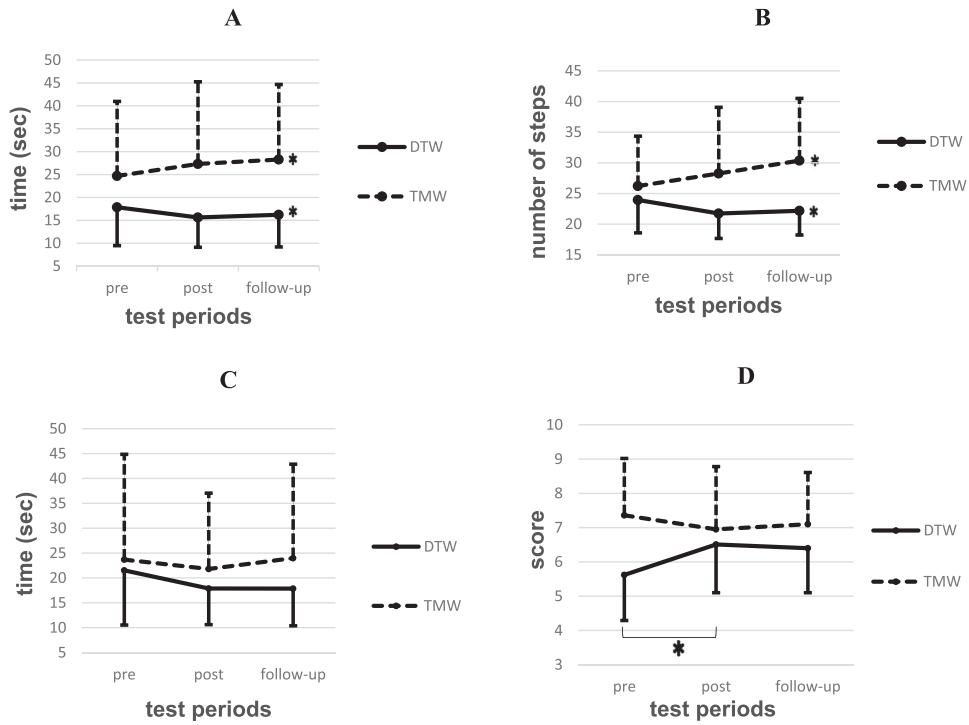

Figure 1. *Findings across groups and time in the walking-related variables.*

Notes: A = 10-m walk (10 mW m/s); B = number of steps completed during the 10-m walk (10 mW steps); C = Timed Up and Go test (TUG); D = Activity-Specific Balance Confidence Scale (ABC); * = significant at $P < .05$.

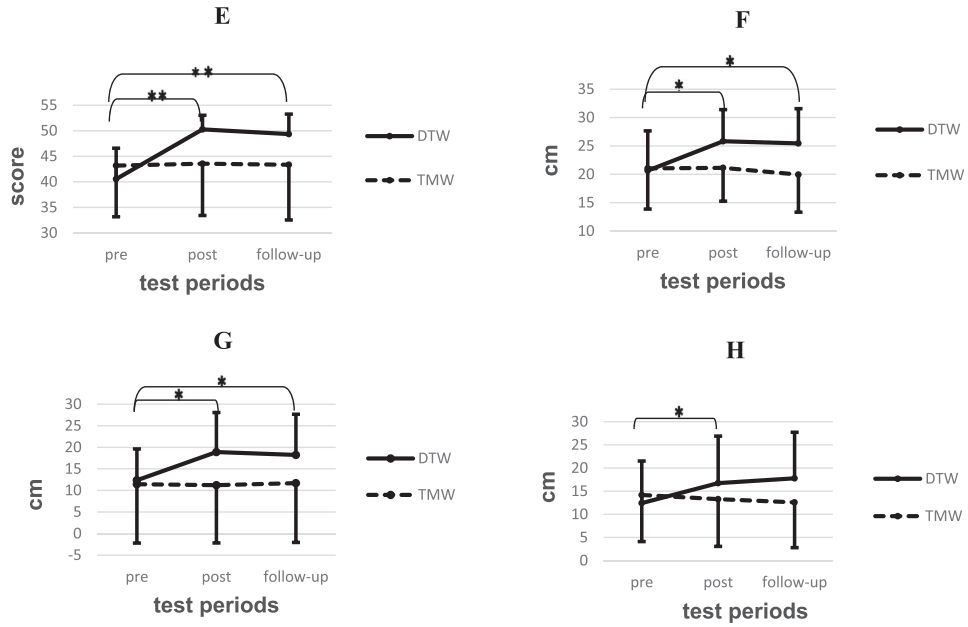

Figure 2. *Findings across groups and time in the other balance-related variables.*

Notes: E = Berg Balance Scale (BBS); F = Functional Reach Test (FRT); G = Lateral Reach Test-Left (LRT-L); H = Lateral Reach Test-R (LRT-R); * = significant at $P < .05$; **significant at $P < .001$.

While improving walking speed is considered to be a very important achievement in the rehabilitation process for people after a stroke,[28] it is important to note that these improvements should be transferred to daily activities, such as walking in the community and actively participating in community life. Results in these areas were not

directly measured in the current study, however such changes can be inferred from the results of the balance and ABC measures (which indicate confidence in stability and mobility skills, without losing balance). Furthermore, in the present study significant improvements were found in the experimental group following the DTW intervention, in the following tests: BBS, FRT, LRT-L, and LRT-R. Improvement in these measurements may indicate greater static and dynamic stability, which is needed in a variety of mobility tasks in the community. These improvements were not found in the control group following TMW. Similar results were found by Cikajlo et al,[29] who examined the effect of VR training on people with stroke and showed a 15% improvement in BBS scores, and by Kang et al,[30] who examined the effect of walking on a treadmill connected to an optical camera, which showed street walking or other landscapes, for people who have had a stroke. Their results showed an improvement of 2.7 cm on the FRT in the experimental group (walking on a treadmill with an optical camera)—that is, about a 9% improvement compared with the control group (not walking on a treadmill, only stretching and working on ranges of motion), which showed no improvement at all.[29,30] In the present study, the experimental group presented a significant improvement of approximately 25% in the FRT test, while the control group presented no change. The improvement in balance performance can be explained by reactive postural control mechanisms that occurred during the VR training, which required increased activation of postural control mechanisms in order to maintain the participants' stability on the treadmill while engaging in the virtual tasks. In the current study, the DTW intervention was designed to improve walking and balance in the community, and therefore the walking was combined with torso and upper body movement. This integration may be compared to street walking while holding shopping bags or while talking on the cell phone. The DTW intervention included a significant distractor from the main task that was based on a tracking and reaching task of the upper extremities, and thereby achieved the necessary additional load on the neuromuscular control system required for obtaining a training effect. We suggest that the control mechanism trained in our study was mainly the primarily automatic reactive mechanism. It was designed to respond to unexpected obstacles or events in which the proactive system is the mechanism that utilizes feedforward control processes, in order to avoid balance perturbations by preparing the body to overcome the forces that undermine its stability.[31] Another explanation for the improvements found in the current study may be related to the task-oriented program that was used in the VR intervention, as was found previously.[27] The fact that the participants had to react to the changing scenes during the DTW, and to achieve different goals while walking, led them to integrate the motor tasks into a complex surrounding. It was found by neuroimaging that VR intervention can induce cortical reorganization of the neural locomotor pathways.[32] However, the specific mechanisms induced by VR intervention need to be determined in further studies.

An additional important outcome of the current study is the improvement in the self-confidence of the participants in the experimental group, as was shown by the improved ABC scores following the DTW intervention. This improvement was clinically significant, as it was measured by a large effect size of .86. This result coincided with the findings of the increased walking speed and larger step length following this intervention.[18] The combination of these findings may indicate a higher level of self-confidence when walking in the community. Similar findings were found in a study by Yang et al,[17] which included training with a VR system on a treadmill to improve walking in the community in persons after stroke. Their results showed a significant improvement in the experimental group, with the average walking quality score of 4.01 compared to 1.33 in the control. We believe that the significant and moderate-to-large ES demonstrated in the current study indicates an increased capability for participating in community activities. Finally, it is important to note that the control (TMW) group did not show any improvement in the various measures, this can be explained by the principle of diminishing returns,[33] all participants were training and experienced in TMW for at least 1 year before the study at the 2 centers, this may have been the reason for the lack of significant improvement in the traditional (TMW) training group. Apparently, the participants needed more stimulation (such as DTW) in order to improve their mobility and stability functions.

Limitations

The current study has several limitations. First, no physiological changes or neurological mechanisms in the brain following the intervention were measured. In order to examine the reactive postural control mechanism, additional methods should be suggested in future studies. Second, although all participants in the study had hemiparesis following stroke, there is still considerable heterogeneity in the damaged brain area that could influence the level of performance following the intervention program.

Conclusions

The improvements observed in the present study demonstrate the potential and utility of VR-based DTW in the use of VR while walking on a treadmill to improve walking and balance in people after stroke. Dual-task training led to greater improvements in comparison to single-task walking, and thus it is suggested to combine different training sessions that require performing multiple tasks at the same time. This can be achieved by using a low-cost

system such as the SeeMe system, as opposed to the sophisticated systems currently on the market.[34] In addition, the use of a VR system has been reported to improve the motivation and enjoyment of participants during training,[35] and it is likely that this was the case while the participants were walking on the treadmill in the current study. Therefore, systems like the one we used can be more practical for community use, where equipment costs could be a barrier.[35] In addition, in view of the development of the technology of smartphones and the potential of connecting them to treadmill screens, it may be possible to develop applications suitable for people after stroke and other populations with difficulties in balance mobility, in order to enable them to be integrated with a task during activity on a treadmill in a regular gym. Finally, further investigations are required to determine the feasibility of these programs in other subpopulations and at different phases after stroke. Moreover, larger groups and long-term between-group comparisons are needed to provide a comprehensive assessment of the efficacy of the treatment.

Declaration of Competing Interest

The authors declare no conflicts of interest.

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