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ORIGINAL ARTICLE

A new device for assessment and training the human balance and coordination: Marmara Balance and Education System (MarBES)

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Abstract

Background Balance and coordination are important for performing activities of daily living. Balance and coordination assessment and training are used by physiotherapists in many different rehabilitation areas. Marmara Balance and Education System (MarBES) is a device developed to evaluate and improve balance and coordination.

Aims To examine the test–retest reliability of the MarBES device.

Methods Double-leg and single-leg (eyes open-closed) tests were applied to healthy young adult participants for balance testing on the MarBES device. Weight data is estimated from pressure sensors located in 4 different corners and a score is calculated with computer software for the individual's center of gravity (center of pressure X, Y) and the amount of deviation from the center for each axis. Weight transfer to the target surface was measured for assessment of the participants' coordination performance. Participants rested for 10 min and all measurements were repeated by the same evaluator. The obtained data were recorded and the reliability of the measurements was evaluated with Spearman's rho correlation analysis.

Results A total of 40 healthy young individuals (28 female) with a mean age of 21 years were included. The balance assessments with MarBES showed moderate to good reliability (ICC: 0.535–0.903). The coordination assessment results showed moderate to good reliability (ICC: 0.575–0.712).

Conclusions Objective evaluation of balance and coordination parameters is very important in rehabilitation. Results of the study showed that the MarBES device developed by the researchers is a reliable method for the evaluation of balance and coordination in healthy young individuals.

Keywords Balance · Coordination · Rehabilitation · Reliability

Introduction

Balance, or postural equilibrium, term involves the alignment of joint segments in an effort to keep the center of gravity within an optimal range of the maximum stability limits [1].

Coordination is defined as the ability to use different body parts together smoothly and efficiently. Balanced and coordinated movements are multidimensional and require the organization of multiple subsystems as the central nervous system, the vestibular system, the musculoskeletal system, the somatosensory system, and the visual system [1, 2].

Balance and coordination are important for people to be able to perform activities of daily living independently. Without adequate balance and coordination, walking can become impossible and even standing can become difficult [4, 5]. Humans were created for a variety of movements and physical activities throughout the day. Balance and coordination are of great importance for smooth, fluid, and purposeful movement [6–8].

Balance and coordination systems must function as a whole to ensure the balance of individuals. Even without health problems, problems with balance and coordination can occur with

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age [1, 5]. In the clinical setting, people receive exercise from physical therapists using various methods to improve their balance and coordination, protect them from injury, and gain independence, and improve sportive performance [1, 3–7].

There is a close connection between somatosensory systems, proprioception, balance, and coordination [1]. Generally, approaches are used to improve balance and coordination by pushing and pulling the patient's body, transferring weight from one lower limb to another on balance boards, and walking exercises in various patterns in clinical practice. Exercises are started on static, bilateral, and stable surfaces and progressed using dynamic, unilateral, and unstable surfaces [6–8].

There are some assessment methods used for balance and coordination assessment in clinical practice, but these provide subjective information to the clinicians [1]. Today, technological devices are being developed to adapt the possibilities in the clinical environment to the new era to objective assessment balance and improve balance and coordination [9, 10]. It is very difficult to access the available technological devices because they are expensive. In addition, many existing devices evaluate only static balance [1, 9]. The aim of this study is to evaluate the reliability of the device "Marmara Balance and Education System (MarBES)" developed in our university within the scope of a TUBITAK project, which can guide the user with visual, auditory, and mechanical notifications and allows both objective evaluation and training for balance and coordination. The system includes software that provides both visual and auditory feedback, as well as an interactive floor.

Methods

This cross-sectional study was conducted at the Biomechanics and Virtual Reality Laboratory, Faculty of Health, Marmara University, Istanbul.

A total of 40 participants were included in this study. All the participants recruited in this study satisfied the inclusion criteria: healthy young adults, aged between 18–45 years, able to stand independently for at least 30 s. Participants were excluded in the presence of any neurological or orthopedic problems that may affect balance and coordination, use of medication that may affect balance, congenital vertebrae and lower extremity deformities, lower extremity surgery in the last 6 months, and sensory, hearing, and vision problems.

Before starting the study, the purpose and methodology of the study were explained in detail to all participants in written and verbal. All participants signed an informed consent form before participating in the study. The study was approved by the Marmara University, Faculty of Medicine, Clinical Research Ethics Committee. All procedures were performed in accordance with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

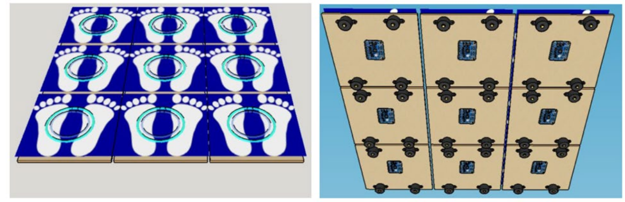

Fig. 1 Top and bottom views of the platform

MarBES is a device developed by the researchers for the evaluation and training of balance and coordination to be used in the training and treatment of the neuro-muscular system. The device consists of software with visual and auditory feedback and an interactive floor. There are pressure sensors and electronic cards that will detect the weight of the individual on the interactive floor (Figs. 1 and 2). The upper part of the floor was produced by adding LED lights designed in the form of footprints so that the person can receive visual and auditory feedback. Software section with visual and auditory feedback; by embedding C-based codes into the Arduino control card, processing the data formed as a result of pressure on the Load-Cell (weight sensors) and transferring them to the interface design on the C# Windows Form, it presents the visual and auditory richness to the operator and the user. Weight data is estimated from pressure sensors located in 4 different corners and a score is calculated with computer software for the individual's center of gravity (center of pressure X, Y) and the amount of deviation from the center for each axis. In the assessment of coordination, the transfer time (reaction) of the determined amount of the individual's weight (for example, 20% of the body weight) to the target surface is measured. Weight transfer to the target surface was measured for assessment of the participants' coordination performance.

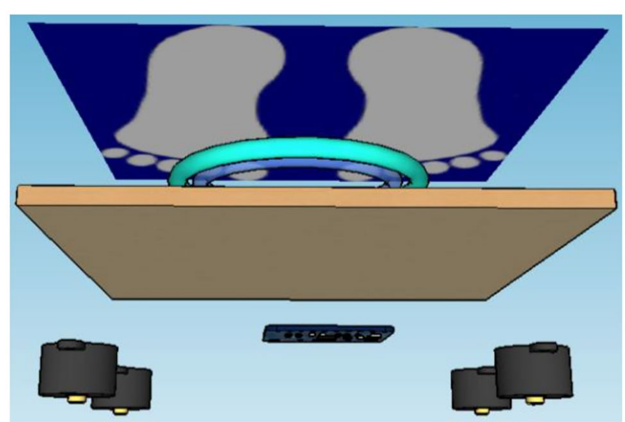

Fig. 2 Weight modules

Participants' balance and coordination were evaluated on the MarBES platform. The participants were asked to stand on the MarBES platform for four conditions: double-leg and single-leg standing with eyes open and closed. Participants rested for 10 min and all measurements were repeated by the same research assistant.

Balance Tests

Participants were asked to stand with their arms at the hips for 60 s on the foot pictures on the platform in the center of the MarBES platform (Fig. 1), with their eyes open and eyes closed. The test was terminated when the subject came out of this position and the time was recorded.

Single-leg balance test was applied for both legs. The subjects were asked to stand unsupported with knee and hip extension on one leg, and their other foot was fixed at the midpoint of the central platform for 30 s. When the arm left the hip or the foot touched the ground, the test was stopped and the time was recorded.

The results of the both double-leg stance and single-leg stance tests were recorded as scores, which were calculated by the developed software based on the deviation of the center of gravity on the X and Y axes.

Coordination assessment

For the coordination assessment, it was requested that while the subject stood on one foot on the 5th surface (center of the platform) (Figs. 3 and 4), the other foot contacted the target area which was red-lighted until it turned green on the MarBES platform without any assistance with arms. The subject transferred 20% of the total weight on the surface in 100 ms, the color change was observed. The order in which they could touch which surface was determined based on the identified patterns by the researchers. The different patterns were used for the right and the left foots. The test was finalized when the subjects touched any other area out of the target. The score was obtained based on the software algorithm including the speed, time, and accomplished task for both feet.

In the center of the MarBES device, when the foot is in the standing position, the weight data detected by the pressure sensors at four different corners under the surface are calculated with the computer software. The calculation formula used here is:

Fig. 3 Red led: target led; and green led: confirmation led

m1, m2, m3, m4: weight data detected by four different pressure sensors

The balance score is calculated in proportion to the absolute value of the deviation of the center of gravity from the axis. According to this formula, the smaller the amount of deviation, the higher the score. The score calculation on the X and Y axes is done separately from each other. Thus, deviations in the balance axis can be evaluated independently. The formula used in the score calculation is as follows:

$$Balance\ score\ X = \int \left(Center\ X - \left|X_{km}\right|\right)$$

$$Balance\ score\ Y = \int \left(Center\ Y - \left|Y_{km}\right|\right)$$

In the coordination test, the individual's time to transfer his weight to the target surface (reaction) is measured. The coordination score is calculated by computer software with the following formula:

$$Coordination\ score = \int (Target\ time - Reaction\ time)$$

The obtained data were analyzed using the SPSS (v16.0) program. Conformity to normal distribution was analyzed using the Shapiro-Wilks test. Descriptive statistics were used for demographic variables. Spearman's correlation coefficients for each measurement were calculated and test–retest reliability was assessed using Spearman's rho correlation analysis (2-tailed). If the p-value is less than 0.05 and the Pearson correlation coefficient is above 0.7, the researchers can have evidence of test–retest reliability.

Center of Gravity X-axis coordinate: $X_{km} = \dfrac{(m_1X - X) + (m_2X - X) + (m_3X - X) + (m_4X - X)}{m_1 + m_2 + m_3 + m_4}$

Center of Gravity Y-axis coordinate: $Y_{km} = \dfrac{(m_1Y - Y) + (m_2Y - Y) + (m_3Y - Y) + (m_4Y - Y)}{m_1 + m_2 + m_3 + m_4}$

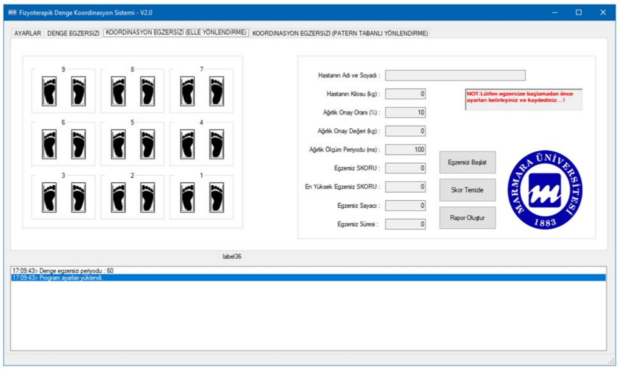

Fig. 4 Coordination exercise screen

Intraclass correlation coefficient (ICC) was calculated for the test–retest reliability. The ICC was interpreted as follows: any score above 0.9 indicates excellent reliability, 0.75–0.9 indicates good, 0.5–0.75 indicates moderate, and values below 0.5 indicate poor reliability [11, 12].

Results

Twenty-seven of the participants were women (70%). The median age was 21 years (IQR 25/75: 20/22 years) and the median BMI was 23.09 (IQR 25/75: 20.66/26.10). The descriptives of the balance and coordination tests are presented at Tables 1 and 2.

The balance score results are measured in the X and Y axes of the center of gravity when both feet are in the standing position on the foot; pictures in the square in the center of the device are shown in Fig. 1. According to these results, the double-standing balance scores of the participants were found to be quite high (X: 93.27–95.66; Y: 87.78–88.98).

The double-leg stance test showed a moderate (ICC = 0.535) and a good (ICC = 0.871) reliability for the X and Y axes in eyes open condition (Table 1). Among repeated measurements, there was moderate correlation in the X axis scores ($r = 0.538$, $p = 0.000$) and high correlation was found in Y axis scores with eyes open conditions ($r = 0.722$, $p = 0.000$, Table 1). In the eyes closed condition test, X axis and Y axis measurements

Table 1 The descriptives of MarBES balance tests and the correlations of the repeated measurements

	Score (%)	Median (IQR: 25/75)	Rho	p	ICC (95% CI)
Double-leg stance (eyes open)	X1	95.66 (92.66/97.18)	0.538	< 0.001*	0.535 (0.143–0.751)
	X2	93.93 (91.65/96.23)			
	Y1	88.04 (80.19/93.41)	0.722	< 0.001*	0.871 (0.756–0.932)
	Y2	88.35 (81.59/92.67)			
Double-leg stance (eyes close)	X1	93.27 (90.15/95.68)	0.699	< 0.001*	0.769 (0.546–0.883)
	X2	93.37 (90.88/95.43)			
	Y1	88.98 (78.21/93.80)	0.609	< 0.001*	0.815 (0.650–0.903)
	Y2	87.78 (80.10/91.21)			
Single-leg stance (right) (eyes open)	X1	93.01 (89.65/96.03)	0.714	< 0.001*	0.754 (0.444–0.843)
	X2	92.48 (89.57/95.81)			
	Y1	80.20 (73.67/88.80)	0.783	< 0.001*	0.852 (0.655–0.930)
	Y2	85.30 (76.68/92.19)			
Single-leg stance (right) (eyes close)	X1	89.42 (76.29/91.72)	0.634	< 0.001*	0.777 (0.576–0.882)
	X2	89.07 (76.47/91.68)			
	Y1	71.37 (61.39/80.01)	0.462	0.003*	0.755 (0.537–0.870)
	Y2	74.00 (65.48/83.40)			
Single-leg stance (left) (eyes open)	X1	89.02 (84.98/93.52)	0.513	< 0.001*	0.903 (0.817–0.949)
	X2	88.47 (84.46/93.32)			
	Y1	87.39 (76.86/93.63)	0.686	< 0.001*	0.796 (0.616–0.892)
	Y2	87.94 (76.93/92.49)			
Single-leg stance (left) (eyes close)	X1	78.75 (50.48/87.66)	0.563	< 0.001*	0.802 (0.627–0.895)
	X2	78.52 (44.06/87.53)			
	Y1	69.75 (48.73/81.45)	0.617	< 0.001*	0.767 (0.562–0.877)
	Y2	61.27 (42.67/82.17)			

Spearman's rho correlation analysis was used

IQR 25/75 interquartile range 25/75, *1* 1st assessment, *2* 2nd assessment

*$p < 0.05$

Table 2 The descriptives of MarBES coordination tests and the correlations of the repeated measurements

	Score (%)	Median (IQR: 25/75)	Rho	p	ICC (95% CI)
Coordination	Right 1	72.47 (66.59/77.44)	0.585	< 0.001*	0.575 (− 0.143 to 0.823)
	Right 2	79.33 (75.84/81.57)			
	Left 1	78.57 (73.62/80.75)	0.690	< 0.001*	0.712 (0.368 to 0.860)
	Left 2	80.36 (77.06/82.53)			

Spearman's rho correlation analysis was used

IQR 25/75 interquartile range 25/75, *1* 1st assessment, *2* 2nd assessment

*$p < 0.05$

of the double-leg stance test showed a good level of reliability (ICC = 0.769, ICC = 0.815) (Table 1). Moderate correlations were found in the X and Y axis scores in the eyes open conditions ($r = 0.699$, $p = 0.000$; $r = 0.609$, $p = 0.000$, Table 1).

The single-leg stance test scores were calculated based on the deviation in the X and Y axes of the center of gravity while standing on one leg are shown in Table 1. The single-leg standing balance scores of the participants were also quite high. The X axis and Y axis of the right foot standing balance test showed a good degree reliability (ICC = 0.704, ICC = 0.852) (Table 1). A good degree test–retest reliability was found (ICC = 0.777, ICC = 0.755) for the X and Y axes of right foot standing in eyes closed condition (Table 1). An excellent test–retest reliability (ICC = 0.903) was found for X axis and a good degree of reliability for Y axis (ICC = 0.796) of the left foot standing balance test in eyes open condition, while the X and Y axes showed good reliability (ICC = 0.802, ICC = 0.767) in eyes closed condition (Table 1). While there was a moderate correlation in the X and Y scores of the right foot eyes closed ($r = 0.634$; $r = 0.462$; $p = 0.000$ respectively) and the left foot eyes open ($r = 0.513$; $r = 0.686$; $p = 0.000$ respectively) and closed ($r = 0.563$; $r = 0.617$; $p = 0.000$ respectively), there was a high level of correlation in the right foot eyes open X and Y scores between both measurements.

The coordination test performed with weight transfer of 20% of the person's weight and the measurement time adjusted to 100 ms indicate that the coordination performances of the participants were at a good level (72.47–80.36). While good degree test–retest reliability was found (ICC = 0.575, ICC = 0.712) for coordination tests, a high level of correlation was found between the repeated measurement scores for the right and left legs ($r = 0.585$; $r = 0.690$; $p = 0.000$ respectively, Table 2).

The results of the balance scores calculated according to the COP data obtained from the single- and double-foot balance evaluation of the participants and the coordination scores calculated according to the reaction times show that the test–retest reliability of the MarBES device is at a valid and acceptable level.

Discussion

The results of this study showed that the MarBES device developed by the researchers was reliable in repeated measurements in balance and coordination assessment. The reported data can be considered useful for measuring balance and coordination tests, and identifying the interventions designed to improve physical function in healthy populations.

Balance is defined as the ability to maintain body orientation in space under static and dynamic conditions, interpreted as postural stability at rest and during active movement or in response to external perturbations. The visual system, vestibular system, and somatosensory receptors in the muscles, bones, and skin provide information from the environment, this multisensory information is integrated in the central nervous system, and posture is achieved by commands to the muscles. Adaptation to the environment is achieved by reactive postural responses and anticipatory postural adjustments [13–15].

The capacity for coordinated movement is the capacity for fluid, precise, and controlled action. Multiple joints and muscles must be coordinated to move in a fluid, effective, and precise manner. This requires that they be triggered at the right time and with the right amount of force. The sequencing, timing, and grading of the activation of several muscle groups are thus the basis of coordination. Coordination, like balance, is achieved by integration of visual, vestibular, and sensory inputs in the central nervous system. The cerebellum and basal ganglia also play an important role in maintaining coordinated movements [13, 16]. In many neurological diseases, both balance and coordination are affected. This is because the neuro-muscular system needs to work in coordination for good balance. Similarly, if a person cannot maintain a good balance, he/she will have difficulty in performing coordinated movements for a purpose. Physiotherapists perform both balance and coordination assessment and rehabilitation not only in the field of neurology but also in different areas such as pediatrics, geriatrics, orthopedic trauma, and post-surgery [13–18].

In this study, since computerized systems that can make standardized measurements are expensive and difficult to access, within the scope of a TÜBİTAK project, it was aimed to develop a device that would allow the evaluation and clinical operation of balance and coordination in cooperation with the physiotherapy and engineering departments of our university and to test the measurements of this device.

The main goal of balance control is to maintain the stability of the body by managing the relationship between the center of mass (COM) and base of support (BOS). If the person can maintain the center of mass within the base of support, there is balance. The two main biomechanical variables used in the assessment of balance problems are COP and center of mass (COM). The COP is the vector point of the total ground reaction force, and the COM refers to the average position in 3D space of segments of the body in accordance with their specific masses. COM may be a deliberate representative of the drives of the complete human corpse [13]. Most of the balance assessment systems used in laboratories and clinics, which include a force platform, evaluate these two parameters and provide valid and reliable measurements [10, 13]. In the device developed by the researchers and presented in this article, the COP change of the person in the X and Y axes was recorded and evaluated by means of sensors placed under the platform.

The test–retest method was carried out to verify the reliability of the developed device. The MarBES has proven to present acceptable reliability. The ICC results indicated that balance assessments were stable under varying conditions such as eyes open and eyes closed. Analyses showed that coordination assessments were reliable, albeit at a lower level than balance assessments.

Balance systems computer-aided can provide objective evaluations that have been proven to give valid and reliable results in different populations. Biodex Balance System and Wii are among the most frequently used assessment devices. Hinman described the differences in test-retest reliability of balance measures produced by the Biodex Balance System in a summary of four studies. Test-retest reliability of the subjects' limits of stability and overall stability index were both computed. The ICC for the overall stability index ranged from 0.44 to 0.89 for the static balance tests. The ICCs for the limits of stability tests, on the other hand, ranged from 0.64 to 0.89, demonstrating less variability than static measures [19]. Wikstrom et al. reported that the reliability of Wii Fit balance activity scores ranged from good to poor (ICC = 0.80 to 0.39), with 8 activities having poor reliability [20]. However, Chang et al. reported that the Wii Fit balance board had a good intraclass correlation (0.86–0.99) for older adults [21]. The different results obtained in different studies evaluating the balance board may be due to differences in the methodology of the studies. While Wikstrom et al. used activities such as deep breathing, tree, standing knee, palm tree, single-leg extension, single-leg bending, side leg raising, basic balance, agility, walking, stability, and single-leg stance in their study, Chang et al. evaluated the activities of standing on both feet with eyes open, standing on both feet with eyes closed; and standing on one leg with eyes open on the dominant leg, similar to our study [21]. In the present study, the ICC values of balance assessment with MarBES device are between 0.535 and 0.903. The fact that we found a moderate level of reliability regarding the X axis in the double-leg stance test scores may be related to the software algorithm of the device and it is aimed to update the software with different algorithms in the future.

On the other hand, computer-based systems or several test batteries including multiple clinical tests are used for coordination assessments. Some tests focus on the number of repetitions in a certain period of time; the others focus on how accurately the task is done and evaluated by the ordinal rating scale. With the development of technology, robot-assisted coordination evaluations have also come to the fore. Hand dexterity assessments in multiple sclerosis (MS) patients and limb dexterity and interlimb coordination in stroke patients can be performed by robot-assisted systems [17, 22, 23]. Additionally, robotic tasks and measures have been used successfully to quantify impairment of children with cerebral palsy (CP) [24]. Gaming technology has been used for task-based therapy, the improvement in the coordination, endurance, or strength is usually interpreted based on the score of the game [25]. However, therapists will need to monitor motor performance. Besides, many robotic tasks include multiple performance parameters, so interpretation of results and identification of impairment can be difficult, especially when multiple tasks are completed. Although the coordination testing is a part of neurological examination, the psychometric properties of many tests are unknown. Clinicians may prefer to use certain tests more than others; coordination test selection should be based largely on their validity, reliability, and responsiveness in the tested population.

It has been reported in the literature that the KINARM robotic exoskeleton is used for upper extremity coordination assessment in neurological diseases. The researchers found a moderate to high correlation between some clinical assessments and KINARM assessment, but did not test the reliability of the measurement [24, 26]. Some gait analysis systems have also been used to assess lower limb coordination [27]. Validity and reliability studies of systems assessing both balance and coordination are very limited in the literature. Therefore, we think that our study will contribute to the literature.

The MarBES device has the advantage of evaluating both coordination and balance, in contrast to other devices. Furthermore, it gives the chance to assess how well one can balance while standing on one leg, both statically and with the other leg extended in various directions. Changes in seconds, distance, or COP are displayed as evaluation results in other devices or clinical tests that assess balance. The software in the MarBES device generates a single score. The software that will be improved in the future will attempt to calculate the COP change with greater accuracy.

This study provided evidence regarding the test–retest reliability of MarBES device. Although it is not possible to talk about a single gold standard test for balance or coordination assessments, investigations of the correlations between some clinical tests' results and MarBES measurements could be useful. Moreover, the sample tested was entirely made up of healthy young adults. There is a need to validate the measurement properties and algorithms in different conditions, such as musculoskeletal, neurologic, or systemic diseases.

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Data availability The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval All the procedures performed in the studies involving human participants were in accordance with the ethical standards of the Ethics Committee of the Faculty of Medicine, Marmara University (Approval Number: 09.2017.257) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

Consent to participate We certify that no party having a direct interest in the results of the research supporting this article has or will confer a benefit on me or on any organization with which we are associated. This cross-sectional study was conducted at the Biomechanics and Virtual Reality Laboratory, Faculty of Health, Marmara University, Istanbul.

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