REVISTA NEUROCIÊNCIAS

Assessment of motor learning using a mobile device and association with anxiety: RCT

Avaliação da aprendizagem motora por meio de dispositivo móvel e relação com a ansiedade: ECR

Evaluación del aprendizaje motor a través del dispositivo móvil y relación con la ansiedad: ECR

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Resumo

Introdução. Aprendizagem motora (AM) representa um conjunto de mudanças internas e permanentes na capacidade do indivíduo de executar uma tarefa motora. Essa pode ser influenciada pela complexidade da tarefa e pela ansiedade. **Objetivo**. Avaliar a AM por meio do teste de trilhas gamificado e correlacionar os dados com ansiedade em universitárias. **Método.** A amostra foi constituída por 33 universitárias, entre 18 e 25 anos, destras, randomizadas em dois grupos, G1, n=16, parte A e G2, n=17, parte B do teste de trilhas gamificado. A ansiedade foi avaliada pelo Inventário de Ansiedade Traço-Estado (IDATE). Aplicou-se o teste *Komolgorov-Smirnov* para normalidade dos dados, posteriormente, os testes de *Mann-Whitney* e Teste t para caracterização da amostra. Os testes de *Friedman* e *Wilcoxon* para a comparação intra e intergrupos. A correlação da variável independente ansiedade-traço, com a variável dependente erro, utilizou-se o teste de Correlação de *Spearman*. **Resultados.** Na avaliação intergrupos, observou-se diferença significante no tempo dos ambientes 1 (p=0,006), 4 (p=0,040) e 6 (p=0,034), e no número de erros nos ambientes 1 (p=0,004), 4 (p=0,023) e 5 (p=0,027). Na avaliação intragrupo, foi observada diferença significante entre quase todos os ambientes nas variáveis tempo e erro para ambos os grupos. Houve correlação positiva moderada entre IDATE-traço e erro nos ambientes 2 (p=0,015; r=0,581) e 4 (p=0,032; r=0,520) do G2. **Conclusão.** Conclui-se que o uso do teste de trilhas modificado por gamificação neste estudo reflete os aspectos da AM, a qual é diretamente influenciada por fatores como dificuldade da tarefa e ansiedade.
Unitermos. Destreza motora; Reabilitação; Testes de memória e aprendizagem

Abstract

Introduction. Motor learning (AM) represents a set of internal and permanent changes in the individual's ability to perform a motor task. This can be influenced by the complexity of the task and anxiety. **Objective.** To evaluate motor learning using the gamified Trail Making Test and correlate the data with anxiety in female university students. **Method.** The sample was comprised 33 right-handed female university students between 18 and 25 years of age randomized to two groups: G1 (n=16) – part A of the gamified Trail Making Test; G2 (n=17) – part B of the gamified Trail Making Test. Anxiety was assessed using the State-Trait Anxiety Inventory (STAI). Normality of the data was determined using the Komolgorov-Smirnov test. The Mann-Whitney test and t-test were used for the characterization of the sample. Intra-group and inter-group comparisons were performed using the Friedman and Wilcoxon tests. The correlation with the independent variable (STAI-trait) and the dependent variable (errors on the test) was determined using Spearman's correlation test. **Results.** In the inter-group

analysis, significant differences were found in the time required to complete environments 1 (p=0.006), 4 (p=0.040), and 6 (p=0.034) as well as the number of errors in environments 1 (p=0.004), 4 (p=0.023), and 5 (p=0.027). In the intra-group analysis, significant differences were found among nearly all environments for time and number of errors in both groups. A moderate positive correlation was found between the STAI-trait and number of errors in environments 2 (p=0.015, r=0.581) and 4 (p=0.032, r=0.520) in G2. **Conclusion.** The use of the Trail Making Test modified by gamification in this study reflects aspects of motor learning, which is directly influenced by factors such as the difficulty of the task and anxiety.
Keywords. Motor dexterity; Rehabilitation; Memory and learning tests

Resumen

Introducción. El aprendizaje motor (AM) representa un conjunto de cambios internos y permanentes en la capacidad del individuo para realizar una tarea motora. Esto puede estar influenciado por la complejidad de la tarea y la ansiedad. **Objetivo.** Evaluar la AM a través del test de senderos gamificados y correlacionar los datos con la ansiedad en estudiantes universitarios. **Método.** La muestra estuvo constituida por 33 estudiantes universitarios, entre 18 y 25 años, diestros, aleatorizados en dos grupos, G1, n=16, parte A y G2, n=17, parte B del test de senderos gamificados. La ansiedad fue evaluada por el *State Trait Anxiety Inventory* (STAI). La prueba de Komolgorov-Smirnov se aplicó a la normalidad de los datos, más tarde las pruebas de Mann-Whitney y la prueba T para la caracterización de la muestra. Las pruebas de Friedman y Wilcoxon para la comparación intra e intergrupal. La correlación de la variable independiente ansiedad-rasgo, con la variable dependiente del error, se utilizó la prueba de correlación de Spearman. **Resultados.** En la evaluación intergrupal se observó diferencia significante en el tiempo de los ambientes 1 (p=0,006), 4 (p=0,040) y 6 (p=0,034), y en el número de errores en los ambientes 1 (p=0,004), 4 (p=0,023) y 5 (p=0,027). En la evaluación intragrupal, se observó una diferencia significante entre casi todos los ambientes en las variables tiempo y error para ambos grupos. Hube correlación positiva moderada entre el rasgo STAI y el error en los ambientes 2 (p = 0,015, r = 0,581) y 4 (p = 0,032, r = 0,520) en G2. **Conclusión.** Se concluye que el uso de la prueba de trail modificada por gamificación en este estudio refleja los aspectos de la AM, que está directamente influenciada por factores como la dificultad de la tarea y la ansiedad.
Palabras clave. Destreza motora; Rehabilitación; Pruebas de memoria y aprendizaje

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INTRODUCTION

Acquiring new movement abilities is essential throughout life and the practice of these abilities is fundamental to motor learning, which regards a set of permanent internal changes in the capacity to execute a motor task in a refined way[1,2].

In temporal terms, motor learning has an initial execution phase, followed by consolidation until reaching the final retention phase. These phases are described in three

stages: the cognitive or acquisition stage, which involves perception and the development of a motor program and is characterized by a large quantity of performance errors and high level of cognitive processing; the associative or consolidation stage, which involves a smaller number quantity of errors and a reduction in cognitive monitoring, with gradual improvement; and the autonomous or adaptation stage, which encompasses the most important aspects of the task, in which the movements are refined with practice, becoming more precise and standardized, with the occurrence of stabilization or reorganization in the presence of new situations[2-5].

While practice is an important factor to faster and improved motor learning[2], emotional issues, especially anxiety, can be limiting. This emotional condition leads to attention deficit and a high level of worry, hampering concentration on a given task and the efficient processing of information. Movements can become less precise, with the occurrence of a larger number of errors and a greater number of attempts or longer period may be needed for the successful execution of the task, which often leads to a reduction in performance, mainly hampering the initial phase of motor learning[6].

As motor learning involves neural and cognitive processes, it cannot be measured directly and is therefore inferred through observation and the quantification of motor behavior with the aid of performance curves. Such curves are represented in graphic form with values achieved during

the execution of a motor task, enabling the determination of an improved performance over the course of various attempts and stabilization, if the subject is not disturbed by external stimuli[2].

Among the different ways to assess the execution of a task, the Trail Making Test (TMT) is used to assess executive functions associated with planning. The degree of complexity imposed by the tasks requires the mobilization of cognitive resources, which is essential to motor learning[2-7]. The original form of the TMT is on paper. However, several studies have used the test in digital versions, some of which are structurally like the original[7-9] and others have involved a game designer[2-10].

The instrument used in the present study is a gamified version of the TMT divided among eight virtual environments for each part of the test. The first is considered 'acquisition'; the second to fifth are for training; the sixth is considered 'retention' and the seventh and eighth are considered 'immediate transference". The seventh is performed with the same trail as the sixth but with the non-dominant hand and the eighth is performed with the same trail as the sixth but in mirrored form and with a dark background.

Mobile devices are promising tools for the health field due to the ease of use and the possibility of creating attractive, fun, stimulating, virtual environments. Thus, tools such as gamification (the design of electronic games with the aim of involving individuals in the solution of a problem) are

used to enhance learning and the absorption of information[2-7].

As knowledge of the mechanisms, processes involved and factors that affect motor learning is fundamental to physiotherapists, the use of simple instruments that are easy to administer can contribute to assessment and treatment strategies and enable individuals to acquire new motor abilities. Therefore, the aim of the present study was to assess motor learning with the use of a gamified version of the Trail Making Test based on a study conducted in 2019[2] and identify factors that exert an influence on motor learning. The hypothesis is that the use of trails reflects aspects of motor learning, which is influenced by factors such as the difficulty of the task and anxiety.

METHOD

Sample

A methodological study with a quantitative approach was conducted with the intention of improving technological resources through the creation and evaluation of a reliable instrument[11]. The study is characterized as a prospective, randomized, single-blind, two-arm, parallel, clinical trial.

This project received approval from the Human Research Ethics Committee on opinion 2.893.122. The study was conducted in accordance with the ethical norms stipulated in Resolution 466/12 of the National Board of Health, assuming the commitment to respect the integrity and autonomy of the participants. Confidentiality of the data

and anonymity of the identity of the participants was assured. The volunteers agreed to participate by signing an informed consent, which was sent by e-mail and considered a prerequisite for the installation and use of the application. This study was registered with the Brazilian Clinical Trials Registry under number RBR-6n6cdx8 on October 27, 2021.

Procedure

The study was developed in the period from October 2018 to October 2021. Recruitment was performed in June and July 2021.

The study was conducted online in the homes of the participants, who were instructed to be in a room seated appropriately in front of a table with their portable electronic device with the Android 7 or better operating system, which was used for the test. After receiving the access link and all information necessary for installation via e-mail, the participants themselves installed the application with the digital version of the TMT on their devices.

Participants were recruited from all periods of the physiotherapy course of a university in the state of Minas Gerais, through an invitation sent via institutional e-mail. Volunteers who agreed to participate signed the informed consent and completed the questionnaires for the initial assessment through the *Google Forms* platform. Based on the answers to the questionnaires, the following inclusion criteria were considered: the female sex, self-declaration of

right handedness, age between 18 and 25 years and no previous experience with the task. Individuals with evident or proven signs of adverse general health conditions, musculoskeletal disorder of the right upper limb, left handedness and those without a mobile device with the Android 7 or better operating system were excluded.

The age group was selected based on the study by Erik Erikson (1980) regarding the stages of psychosocial development in adulthood, who established 18 to 25 years as the first stage of adulthood and individuals in this age range are considered young adults[12].

Participants who met the eligibility criteria were randomized by a blinded independent researcher using the *Randomizer* site which generated a random allocation sequence with two groups: G1 – application with TMT containing numbers alone (Part A); G2 – application with TMT containing numbers and letters (Part B).

Randomization was performed according to the answers sent through *Google Forms*, which were used for the application of the inclusion and exclusion criteria and randomization was performed weekly. Block 1 was randomized on June 10, 2021, with ten students distributed – five in each group. Block 2 was randomized on June 17, 2021, with 19 participants distributed – 10 in G1 and 9 in G2. Block 3 was randomized on June 24, 2021, with 12 students distributed – six in each group.

A total of 41 participants were randomized – 21 in G1 and 20 in G2. At the end of the process, five participants

dropped out from G1 and three dropped out from G2. Thus, the final sample comprised 33 participants (17 in G1 and 16 in G2).

Based on the group to which the volunteer was allocated, the installation file of the application containing the test to be taken was sent via e-mail, along with all instructions in a guide designed for this purpose. After installation and the execution of the application, the results were sent via the *WhatsApp* application to the head researcher in image format. The data were tabulated in the Excel program and sent for statistical analysis by another researcher who was unaware of the allocation of the participants to the different groups.

For the selection of the sample, the Hand Dominance Test[13] was used (only right-handed participants were included), along with a form created by the researchers addressing health-related aspects, such as upper limb impairment.

The State-Trait Anxiety Inventory (STAI) developed by Spielberger, Gorsuch and Lushene (1970) and translated into Portuguese by Biaggio and Natalício (1977)[14] was used. This instrument has 40 statements distributed in two parts. The first part addresses state anxiety and has 20 statements corresponding to the intensity of feelings occurring at the time. The second part addresses trait anxiety with 20 statements corresponding to the frequency of symptoms scored on a scale of 1 to 4 points. The total of each part ranges from 20 to 80 points, with higher scores indicating

higher levels of anxiety[15-17]. The second part of the test (STAI-trait) was used in the present study, since the first part requires direct supervision, and the study was conducted remotely in the period of the COVID-19 pandemic.

The application developed using the gamification process was adapted and divided into 16 environments (eight in Part A and eight in Part B). Similar sizes and spatial configurations were used in both parts so that the performance could be determined with the same paths and distances travelled in each environment.

The eight environments in TMT-A were subdivided into environment 1A, with numbers 1 to 10, considered the task comprehension environment; environments 2A, 3A, 4A and 5A were considered task training environments, with environment 2A containing numbers 1 to 12; 3A numbers 1 to 16; 4A numbers 1 to 20; and 5A numbers 1 to 24 for the verification of the acquisition of the ability. Environment 6A, considered the retention environment, consisted of numbers 1 to 26. Environment 7A, considered bilateral transference, had the same format as environment 6A but the participant was instructed to perform the test with the left (non-dominant) hand. Lastly, environment 8A, which had the same format as environment 6A but was mirrored and with a dark background, was considered the immediate transference-adaptation test.

The eight environments in TMT-B were also subdivided: environment 1B consisted of letters (A-E) and numbers (1-5) and was considered the adaptation phase and

understanding of the task. Environments 2B, 3B, 4B, 5B and 6B were task training environments; environment 2B consisted of letters A to F and numbers 1 to 6; 3B comprised letters A and H and numbers 1 to 8; environment 4B comprised letters A to J and numbers 1 to 10; and environment 5B comprised letters A to L and numbers 1 to 12; these environments were considered ability acquisition tests. Environment 6B was composed of letters A and M and numbers 1 to 13. Environment 7B consisted of the same format as environment 6B but was performed with the left (non-dominant hand) and environment 8B consisted of the same format at environment 6B but was mirrored and with a dark background.

The tests were performed individually by the participants in their homes following the instructions provided by the researchers and described on the initial screen of the application. All participants received the same instructions regarding the procedures of the study. The only difference was the information on trails that contained numbers alone and those the comprised numbers and letters.

The dependent variables "number of errors" and "time" were considered for the analysis of the participants' performance. The adaptation and training phases were characterized by the exposure to sequential interaction opportunities with sequenced movements based on a TMT. After the training phase, the participants performed the test in environment 6, which was considered the retention test,

followed by the test in environment 7 for the determination of two-handed immediate transference and the test in environment 8, considered the immediate transference-adaptation test.

Statistical Analysis

The data were tabulated in the Excel program and sent for statistical analysis by an independent researcher blinded to the allocation to the different groups. Descriptive statistics was performed with the calculation of percentage, mean and standard deviation values. Statistical analysis was conducted with the aid of the *Statistical Package for the Social Sciences* (SPSS version 20.0). The *Komolgorov-Smirnov* test was used to determine the distribution (normal or non-normal) of the data. The *Mann-Whitney* test and t-test were used for the characterization of the sample. Intra-group and inter-group comparisons were performed using the *Friedman* and *Wilcoxon* tests. The correlation between the independent variable (STAI-trait) and the dependent variable (errors on the test) was determined using *Spearman's* correlation test. A *p*-value ≤ 0.05 was considered indicative of statistical significance on all tests.

RESULTS

Two hundred seventeen female students were recruited via e-mail in the period from June to July 2021, 60 of whom completed the form addressing health aspects and upper limb impairment as well as the Hand Dominance Test. Based

on the answers on the form, the inclusion and exclusion criteria were applied and 41 participants were randomized to the two groups (G1: n=21; G2 n=20) by a blinded independent researcher. Among the 41 volunteers randomized, 33 (16 in G1 and 17 in G2) performed the tests on the application and sent the results for analysis.

Thirty-three female students of physiotherapy course and self-declared right-handed met the eligibility criteria and were included in the present study. The participants were randomly allocated to two groups (G1 and G2). G1 comprised 17 participants with a mean age of 22.25±1.65 years and G2 comprised 16 participants with a mean age of 20.76±1.64 years. The characterization of the sample in both groups is presented in Table 1. No significant differences were found between groups regarding the descriptive measures.

Table 2 displays the results of the comparison between environments in G1 with regards to the variables time and number of errors. For time, significant increases were found in the comparison between environments 1 and 3 (p=0.001), 1 and 4 (p=0.001), 1 and 5 (p=0.000), 1 and 6 (p=0.000), 1 and 7 (p=0.000), and 1 and 8 (p=0.000); environments 2 and 3 (p=0.001), 2 and 4 (p=0.000), 2 and 5 (p=0.000), 2 and 6 (p=0.000), 2 and 7 (p=0.000); and 2 and 8 (p=0.000); environments 3 and 4 (p=0.006), 3 and 5 (p=0.000), 3 and 6 (p=0.001), 3 and 7 (p=0.001), and 3 and 8 (p=0.000); environments 4 and 5 (p=0.001), 4 and 6 (p=0.002), 4 and 7 (p=0.001), and 4 and 8 (p=0.001);

Table 1. Characterization of sample.

Characteristics	Randomized (n=33)		
	G1 (n=16)	G2 (n=17)	p-value
Participants			
Age (years)	22.25±1.65	20.76±1.64	0.87[a]
Declared right-handedness	100 (16)	100 (17)	-
Semester of course			-
1st semester	6.25 (1)	17.65 (3)	-
3rd semester	6.25 (1)	35.29 (6)	-
5th semester	12.50 (2)	11.76 (2)	-
7th semester	37.5 (6)	29.41 (5)	-
8th semester	18.75 (3)	-	-
10th semester	18.75 (3)	5.88 (1)	-
Device (Android)	100 (16)	100 (17)	-
Health problem			-
Yes	18.75 (3)	41.18 (7)	-
No	81.25 (13)	58.82 (10)	-
Type of health problem			-
Hypertension	6.25 (1)	5.88 (1)	-
Rhinitis	6.25 (1)		-
Tested positive for COVID-19	6.25 (1)	-	-
Sinusitis	-	5.88 (1)	-
Congenital scoliosis	-	5.88 (1)	-
Muscle tension in back	-	5.88 (1)	-
Diabetes mellitus I	-	5.88 (1)	-
Hypothyroidism	-	55.88 (1)	-
Reflux and gastritis	-	5.88 (1)	-
Not applicable	81.25 (13)	58.82 (10)	-
Dominance test	9.38±0.96	9.82±0.53	0.09[b]
STAI-state	45.38±4.38	46.47±3.34	0.42[a]
STAI-trait	49.69±7.40	48.88±5.59	0.29[a]

G1 = Group 1; G2 = Group 2; Variables age, dominance test and STAI expressed as mean±standard deviation; other variables expressed as percentage - % (n); [a]*Mann-Whitney test*; [b] t-test.

environments 5 and 7 (p=0.003), and 5 and 8 (p=0.015); and environments 6 and 7 (p=0.017). Regarding the number of errors, significant increases were found in the comparison between environments 1 and 6 (p=0.030), 1 and 7

(p=0.005) and 1 and 8 (p=0.020); environments 2 and 3 (p=0.036), 2 and 7 (p=0.003), and 2 and 8 (p=0.013); environments 3 and 7 (p=0.022); environments 4 and 7 (p=0.005), and environments 5 and 7 (p=0.012).

Table 2. Comparison of environments in G1 with regards to time and number of errors.

Environments	Time	Errors
1 (comprehension)	18.85±9.99	0.63±1.31
2 (acquisition)	23.03±9.71	0.75±1.24
3 (acquisition)	39.97±18.32*	2.00±2.19*
4 (acquisition)	55.92±19.96*	2.19±3.67
5 (acquisition)	80.96±24.50*	3.06±6.16
6 (retention)	87.79±32.78*	4.00±6.28*
7 (immediate transference - bilateral)	107.85±47.18*	5.88±6.58*
8 (immediate transference - adaptation)	98.42±29.23*	3.44±4.30*

G1 = Group 1; Data expressed as mean±standard deviation. *$p \leq 0.05$. *Friedman* test followed by *Wilcoxon* test.

Table 3 displays the results of the comparison between environments in G2 with regards to the variables time and number of errors. For time, significant increases were found in the comparison between environments 1 and 4 (p=0.031), 1 and 5 (p=0.001), 1 and 6 (p=0.001), 1 and 7 (p=0.001), and 1 and 8 (p=0.001); environments 2 and 3 (p=0.000), 2 and 4 (p=0.000), 2 and 5 (p=0.000), 2 and 6 (p=0.000), 2 and 7 (p=0.000), and 2 and 8 (p=0.000); environments 3 and 4 (p=0.000), 3 and 5 (p=0.000), 3 and 6 (p=0.000), 3 and 7 (p=0.000), and 3 and 8 (p=0.000); environments 4 and 5 (p=0.000), 4 and 6 (p=0.001), 4 and 7 (p=0.001), and 4 and 8 (p=0.000). Regarding the number of errors, a

significant reduction was found in the comparison between environments 1 and 2 (p=0.025) and significant increases were found in the comparison of environments 2 and 3 (p=0.010), 2 and 4 (p=0.003), 2 and 5 (p=0.001), 2 and 6 (p=0.006), 2 and 7 (p=0.002), and 2 and 8 (p=0.006).

Table 3. Comparison of environments in G2 with regards to time and number of errors.

Environments	Time	Errors
1 (comprehension)	46.54±52.34	7.65±11.52
2 (acquisition)	34.63±13.39	0.94±1.52*
3 (acquisition)	51.43±18.57*	3.18±4.33*
4 (acquisition)	77.55±30.64*	4.82±5.07*
5 (acquisition)	117.44±48.75*	5.59±5.64*
6 (retention)	122.62±56.30*	4.53±5.54*
7 (immediate transference - bilateral)	126.56±44.71*	4.41±4.02*
8 (immediate transference - adaptation)	119.84±33.88*	3.94±4.37*

G2 = Group 2; Data expressed as mean±standard deviation. *$p \leq 0.05$. *Friedman* test followed by *Wilcoxon* test.

Table 4 displays the results of the inter-group comparisons between G1 and G2 with regards to the time spent in the environments. A longer execution time was found in all environments in G2 compared to G1, with significant differences for environments 1, 4, and 6.

Table 5 displays the results of the inter-group comparisons between G1 and G2 with regards to the number of errors in the environments. Except for environment 7, a greater number of errors was found in all environments in G2 compared to G1, with significant differences for environments 1, 4, and 5.

Table 4. Inter-group comparison with regards to time (in seconds) spent in each environment.

Environments	Randomized (n = 33)		
	G1 (n = 16) Mean (95% CI)	G2 (n = 17) Mean (95% CI)	p-value
Environment 1 (comprehension)	18.85 (13.52-24.17)	46.54 (19.62-73.45)	0.006*
Environment 2 (acquisition)	23.03 (17.85-28.20)	34.63 (27.75-41.52)	0.505
Environment 3 (acquisition)	39.97 (30.20-49.73)	51.43 (41.89-60.98)	0.056
Environment 4 (acquisition)	55.92 (45.28-66.56)	77.55 (61.79-93.30)	0.040*
Environment 5 (acquisition)	80.96 (67.91-94.02)	117.44 (92.37-142.50)	0.051
Environment 6 (retention)	87.79 (70.32-105.26)	122.62 (93.67-151.57)	0.034*
Environment 7 (immediate transference - bilateral)	107.85 (82.71-132.99)	126.56 (103.58-149.55)	0.084
Environment 8 (immediate transference - adaptation)	98.42 (82.84-114.00)	119.84 (102.42-137.26)	0.347

G1 = Group 1; G2 = Group 2; CI = confidence interval; *$p \leq 0,05$. *Friedman* test followed by *Wilcoxon* test.

Table 5. Inter-group comparison with regards to number of errors in each environment.

Environments	Randomized (n = 33)		
	G1 (n = 16) Mean (95% CI)	G2 (n = 17) Mean (95% CI)	p-value
Environment 1 (comprehension)	0.63 (-0.07-1.32)	7.65 (1.73-13.57)	0.004*
Environment 2 (acquisition)	0.75 (0.09-1.41)	0.94 (0.16-1.72)	0.643
Environment 3 (acquisition)	2.00 (0.83-3.17)	3.18 (0.95-5.40)	0.619
Environment 4 (acquisition)	2.19 (0.23-4.15)	4.82 (2.22-7.43)	0.023*
Environment 5 (acquisition)	3.06 (-0.22-6.34)	5.59 (2.69-8.49)	0.027*
Environment 6 (retention)	4.00 (0.65-7.35)	4.53 (1.68-7.38)	0.498
Environment 7 (immediate transference - bilateral)	5.88 (2.37-9.38)	4.41 (2.35-6.48)	0.690
Environment 8 (immediate transference - adaptation)	3.44 (1.14-5.73)	3.94 (1.70-6.19)	0.700

G1 = Group 1; G2 = Group 2; CI = confidence interval; *$p \leq 0,05$). Friedman test followed by Wilcoxon test.

The results of the correlation analysis between the STAI-trait score and time (in seconds) spent in the environments as well as between the STAI-trait score and number of errors in the environments in G1 and G2 are displayed in Tables 6 and 7, respectively. No significant correlations were found between the STAI-trait score and either time or errors in G1. In contrast, a significant positive correlation was found between the STAI-trait score and the number of errors in environments 2 and 4 in G2.

Table 6. Correlation between STAI-trait scores and both time (seconds) and number of errors in each environment in G1.

Environments	Time (seconds) Errors	STAI-Trait	r value	p-value
1 (comprehension)	18.85 0.63	49.69	0.301 0.166	0.257 0.540
2 (acquisition)	23.03 0.75	49.69	0.053 0.439	0.845 0.089
3 (acquisition)	39.97 2.00	49.69	-0.174 0.190	0.519 0.480
4 (acquisition)	55.92 2,19	49.69	-0.330 -0.068	0.211 0.801
5 (acquisition)	80.96 3.06	49.69	-0.162 0.138	0.548 0.610
6 (retention)	87.79 4.00	49.69	-0.077 0.394	0.778 0.131
7 (immediate transference – bilateral)	107.85 5.88	49.69	-0.201 0.266	0.456 0.319
8 (immediate transference – adaptation)	98.42 3.44	49.69	-0.248 0.188	0.355 0.487

G1 = Group 1; Variables time, errors and trait expressed as mean; Spearman's correlation test.

Table 7. Correlation between STAI-trait scores and both time (seconds) and number of errors in each environment in G2.

Environments	Time (seconds) Errors	STAI-Trait	r value	p-value
1 (comprehension)	46.54 7.65	48.88	0.149 0.055	0.569 0.833
2 (acquisition)	34.63 0.94	48.88	0.041 0.581	0.877 0.015*
3 (acquisition)	51.43 3.18	48.88	0.039 0.200	0.881 0.442
4 (acquisition)	77.55 4.82	48.88	0.308 0.520	0.229 0.032*
5 (acquisition)	117.44 5.59	48.88	0.359 -0.180	0.157 0.488
6 (retention)	122.62 4.53	48.88	0.091 -0.014	0.729 0.956
7 (immediate transference – bilateral)	126.56 4.41	48.88	0.059 0.100	0.822 0.703
8 (immediate transference – adaptation)	119.84 3.94	48.88	0.260 0.388	0.313 0.123

G2 = Group 2; Variables time, errors and trait expressed as mean; Spearman's correlation test, *p<0.05.

DISCUSSION

The main objective of the present study was to assess motor learning using the Trail Making Test adapted for mobile devices and correlate the data with the level of anxiety in female university students of the physiotherapy course. No significant differences between the two groups were found regarding age, declared dominant side, the device used for the assessment or level of anxiety.

The female sex was chosen for analysis in the present study since most students in physiotherapy course are women and the fact that studies suggest higher levels of anxiety among women in general due to several factors, including hormonal aspects[18].

Right-side dominance was required for inclusion based on a study conducted in 2018[7], in which the authors reported that left-handed individuals required more time to conclude

the Trial Making Test in both the print and digital versions. The increase in time with the use of the left hand is since each element of the test is generally located more to the right of the previous element, making it more difficult to find when the left hand is used[7].

The increase in the complexity of the task (going from one virtual environment to the next with an increase in the sequential order to be followed) led to an increase in the time required to complete the environment as well as the number of errors committed. These results agree with data described in a study conducted in 2019[2] that used a gamified version of the TMT and also found an increase in the number of errors and time required with the progression in the virtual environments. Indeed, the difficulty of the task is one of the factors that influence learning, as the increase in complexity is directly proportional to the quantity of errors and time required for conclusion of the task[19]. According to a study conducted in 2018[19], learning with and without errors is equally effective and the difficulty of the task does not affect the visuomotor magnitude of the learning of abilities but rather the way that learning occurs.

A significant reduction in execution time and the quantity of errors was found in environment 2 in comparison to environment 1 in G2. This may be related to the understanding of the task when it is performed a second time, which agrees with findings described in studies conducted in 2006[20] and 2019[2]. In the remaining acquisition environments, a significant increase in execution time and

the quantity of errors was found in comparison to environment 1 in both groups, as the complexity of the task was increased with the inclusion of new elements.

In the comparison of environment 7 (immediate transference - bilateral) to environment 6 (retention), a significant increase in the execution time and quantity of errors was found in G1, whereas the same did not occur in G2. This result disagrees with findings of the study conducted in 2018[21], in which a greater time was required for the execution of Part B of the TMT with the non-dominant hand, but not Part A. The authors reported that the increase in the execution time for Part B with the non-dominant hand may have occurred due to factors such as the greater distance between elements in Part B, the greater complexity of the task with a consequent increase in the demand for cognitive resources and/or the greater need for corrective movements when the task is performed with the non-dominant hand[21]. In the present study, the adaptation of the TMT for the environment digital was performed such that the sequential elements were in the same places in both Part A and B. Therefore, this factor was not considered to exert an influence on the increase of the execution time for Part B. Another factor to consider is that the tests with the dominant and non-dominant hand were performed by different individuals in the study conducted in 2018[21] and not in a sequential manner with the same individual, as in the present investigation. Prior knowledge of the task, even when performed with different sides (dominant and non-

dominant), may have contributed to the results found in G2 in this study.

In the comparison between environment 8 (immediate transference – adaptation) and environment 6 (retention) as well as between environments 8 and 7 (immediate transference – bilateral), no significant differences were found in either of the two groups, demonstrating a tendency toward stabilization even under different conditions, such as the change in context (mirrored) and the use of the non-dominant hand to make the trails. This stabilization may have occurred due to the same quantity of elements in these environments and due to the fact that these environments were performed close to the time necessary to achieve learning. The authors of the study conducted in 2019[22] found greater learning effects on the eighth trial, suggesting that this is the limit to reach the best performance level[22].

In the inter-group comparison, G2 had a longer execution time compared to G1, with significant differences found for environments 1 (comprehension), 4 (acquisition) and 6 (retention), which agrees with data described in the study conducted in 2019[2]. G2 also committed a greater quantity of errors compared to G1, except for environment 7. Significant differences were found in the comparison of environments 1 (comprehension), 4 and 5 (acquisition). This increase in the quantity of errors in G2 was also reported in a previous study[7], which found that the number of errors contributed to the increase in the time required to complete the trail. Indeed, the increase in the difficulty of a task is

directly related to the number of errors, which tends to increase and can have a negative influence on motor learning. However, it is the content of the information embedded in these errors that shapes the plan of action, assisting in improving the performance[19].

In the correlation analysis, a positive correlation was found between the level of anxiety (STAI-trait) and the number of errors committed in environments 2 and 4 (acquisition) in G2, indicating that a higher level of anxiety leads to a greater quantity of errors in these environments on Part B of the test. These results agree with data reported in a study conducted in 2011[23] involving young individuals with a diagnosis of anxiety disorder, in which a greater execution time was found for Part B of the TMT, suggesting that anxiety affects the efficiency of the tasks and exerts a negative impact on performance[23]. For a better understanding of the correlation between levels of anxiety and motor learning, future studies should also assess anxiety using the state part of the STAI instrument on the same day as the execution of the task.

Knowledge on the mechanisms involved in motor learning and factors that affect motor learning are fundamental for physiotherapists during the assessment and rehabilitation of individuals with movement disorders. The use of simple, easy-to-administer instruments, such as the application developed based on the Trail Making Test, can contribute to assessment strategies and physiotherapeutic treatment and can allow individuals to acquire and resolve

motor activities in daily life by making use of the application in their own homes as a form of motivation to improve learning.

CONCLUSION

The use of both Part A and Part B of the Trail Making Test can reflect aspects of motor learning in healthy young individuals. Despite having the same paths, Part B requires more time and is associated with a greater number of errors, confirming that cognitive aspects and the difficulty of the task exert a direct influence on motor performance and, together with anxiety, affect motor learning. Further studies should be conducted using these comparisons in different samples.

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