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Original Article

THE CONTEXTUAL INTERFERENCE EFFECT IN THE LEARNING OF A MANUAL AIMING TASK

O EFEITO DA INTERFERÊNCIA CONTEXTUAL NA APRENDIZAGEM DE UMA TAREFA DE APONTAMENTO MANUAL

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RESUMO

Pouco se sabe a respeito da associação entre o efeito da interferência contextual (EIC) e medidas cinemáticas. O objetivo do presente estudo foi investigar o EIC nos perfis cinemáticos de velocidade e aceleração do membro superior. Vinte e dois participantes (23,7 ± 3,3 anos) foram alocados em dois grupos de prática: em blocos (GPB) e aleatória (GPA). A tarefa consistiu em acertar três alvos apresentados no monitor em três sequências pré-determinadas o mais rápido e preciso possível. O estudo foi dividido em fase de aquisição e teste de transferência. As variáveis de desempenho foram tempo de reação, tempo de movimento e tempo de resposta e as variáveis cinemáticas foram pico de velocidade, tempo relativo para o pico de velocidade e número de correções para alcançar o alvo. Os principais achados mostraram que o GPA apresentou menor tempo de movimento e de resposta do que o GPB. Análise de regressão indicou que a mudança observada ao longo da prática para a medida de pico de velocidade estava associada à mudança do tempo de reação da fase de aquisição para o teste de transferência. Como o pico de velocidade é uma medida associada à pré-programação, sugere-se que o controle central seja essencial para a observação do EIC.

Palavras-chave: Aprendizagem. Memória. Fenômenos biomecânicos. Cinemática.

ABSTRACT

The association between contextual interference effect (CIE) and kinematic measures has been little investigated. The purpose of this study was to investigate the CIE on velocity and acceleration kinematic profiles of upper limb. Thirty-two subjects (23,7 ± 3,3 years) were assigned to groups of blocked practice (GPB) and random practice (GPA). The task consisted in achieve three targets in three specific sequences as quickly and accurately as possible. The study was designed in acquisition phase and transfer test. The variables of performance were reaction time, movement time, and response time and the kinematic variables were peak of speed, relative time to peak of speed, and number of peak acceleration points. The main findings showed that GPA showed lower movement time and response time than GPB. Regression analysis indicated that change in peak velocity during practice was associated to the change of the reaction time from practice to the transfer test. As peak velocity is a measure related to preprogramming, it is suggested that central control was essential to the CIE.

Keywords: Learning. Memory. Biomechanical phenomenona. Kinematics.

Introduction

During one same session, practice can be organized in a constant way, in which the learner practices only one skill, or in a varied way, when two or more skills or two or more variations of the same skill can be practiced throughout the session. The most investigated varied practice structures are blocked practice and random practice. In blocked practice, all trials of a certain skill are performed together before the next skill is performed, thus enabling a greater repetition and predictability of the practice to the learner (e.g., AAAABBBBCCCC). In random practice, skills are executed without a previous sequence in order to generate a low level of predictability and repetition (e.g., BACABCCAABCCB)[1,2].

The way skills are ordered during practice can generate a degree of interference in learning as a previously practiced task can influence the processing of another one practiced afterwards[3]. This phenomenon is known as contextual interference effect (CIE)[2]. It is accepted in the literature that the non-consecutive repetition of one same ability produces more contextual interference. Thus, it is assumed that a high level of contextual interference would be generated in random practice, whereas a low level would be produced in blocked practice[1]. Practice with high contextual interference demands more from cognitive processes that positively affect learning[4,5].

CIE studies predominantly analyze the product of movement, that is, performance, through variables such as reaction time and movement time. According to Lage et al.[1], there are few studies investigating processes involved in CIE. Learning the processes involved in the acquisition of skills allows inferring about changes in the planning, organization and control of movements. One of the control models most used in the study of manual skills such as aiming is Woodworth's two-stage hybrid model[6]. Movement time is subdivided into two sub-movements. The first corresponds to the initial impulse phase, in which the movement is centrally controlled, pre-programmed, and aims to displace the limb ballistically to the target[7]. Near the end point of the movement, the second sub-movement begins, the so-called current control phase of the movement, characterized by use of feedback[7]. Visual and proprioceptive information on the relative positions of the limb and the target are used for possible adjustments in movement trajectory so the target is hit with precision[6,7]. In sequential aiming skills characterized by changes of direction (e.g., reciprocal aiming), the second sub-movement of a given segment of the movement is influenced not only by corrective processes, but also by implementation processes of the posterior segment.

One way to investigate the processes involved in CIE is by using kinematic analyses of movement. It is assumed that in aiming movements the period of time that precedes peak velocity during the trajectory of the limb refers to the initial impulse phase and, after peak velocity, the current control phase of the movement begins. The number of corrections after peak velocity is achieved by analyzing the number of discontinuities in the acceleration profile[8,9]. One strategy of the motor system is to minimize the total duration of the movement by optimizing the time distribution between the first and second sub-movements. A greater duration and size of the first sub-movement indicate a more efficient motor system control, longer ballistic displacement period and less need for corrections in the second sub-movement[10]. As a hypothesis, it is expected that the more repetitive nature of blocked practice will generate a first greater sub-movement than the random practice would, as well as higher peak velocity and fewer corrections in the second sub-movement. This is due to the possibility of maintaining a more stable planning, thus facilitating the adoption of a strategy with greater emphasis on the central control phase. In this way, better planning would lead to higher peak velocity and fewer adjustments in the second sub-movement compared to random practice. Trial after trial, changes required in random practice would demand greater cognitive effort in both planning and correction of the movement. This type of requirement would lead to a less effective control during practice, but would lead to the development of more flexible control mechanisms that would facilitate the transfer of learning. The neural activation observed when transfer of learning is required is associated with the brain activation verified in the final stage of skill acquisition[11]. Transfer seems to be an accelerated form of learning in which processes experienced at the end of acquisition are superimposed on those required in a near condition in the learning test[12].

Kinematic analysis would therefore enable one to learn the effect of practice structures on the velocity and acceleration profiles of the limbs during the learning process. However, the use of kinematic measures is not common in contextual interference investigations. Thus, the present study aims to investigate the effect of contextual interference on motor learning by analyzing not only motor performance but also changes in motor control through the analysis of the velocity and acceleration kinematic profiles of the upper limb. It is expected that the more repetitive characteristic of blocked practice will allow consistency in planning, making a more central control possible throughout practice. In random practice, due to its non-repetitive nature, this possibility reduces and the current control phase would be more emphasized. However, in the transfer test the inverse effect is expected, that is, greater duration and size of the first sub-movement, higher peak velocity and fewer corrections in the random practice in relation to blocked practice. This hypothesis is based on the logic that the processes experienced at the end of random practice associate more with those required in transfer, thus leading to better performance.

Methods

Sample

Twenty-two college students aged between 18 and 35 years old (23.7 ± 3.3 years), of both sexes, right-handed and inexperienced in the task, participated in the study. The individuals' handedness was confirmed through the Edinburgh Handedness Inventory[13], in which they should present an index above 80 points for the right hand. All volunteers signed a free and informed consent form. The study was approved by the Research Ethics Committee of the University where the study was conducted, under protocol No. CAAE: 13205513.6.0000.5149.

Experimental Design

The subjects were randomly divided into two groups: blocked practice group (BPG) and random practice group (RPG). The BPG performed blocks of trials for each task while the RPG performed the trials for each task in a random sequence.

The study consisted of acquisition phase and transfer test. In the acquisition phase, each group performed 20 trials for each of the three tasks, totaling 60 trials. In the transfer test, which occurred 24 hours after the end of the acquisition phase, the participants performed 10 trilas of a new sequence.

Instrument and task

The motor task was performed on a tablet (WACOM Intuos 3, 200 Hz capture speed, with dimensions of 30 x 30 cm) controlled by MovAlyzer software (Neuroscript, Tempe, AZ, USA) and connected to a microcomputer. To determine the volunteer's handedness index, the Edinburgh Handedness Inventory[13] was applied. To execute the task, the volunteer should move a sensor pen on a tablet so that he could hit the next target only if he hit the previous one, with corrections in the tracing being therefore allowed (Figure 1).

The subjects performed a serial aiming task that mandatorily consisted of hitting three targets in pre-determined sequences. The design of the task consisted of nine targets arranged in three columns with three targets each. Of these targets, three were in evidence (in red) while the others were green (Figure 2). The subjects should hit the red targets.

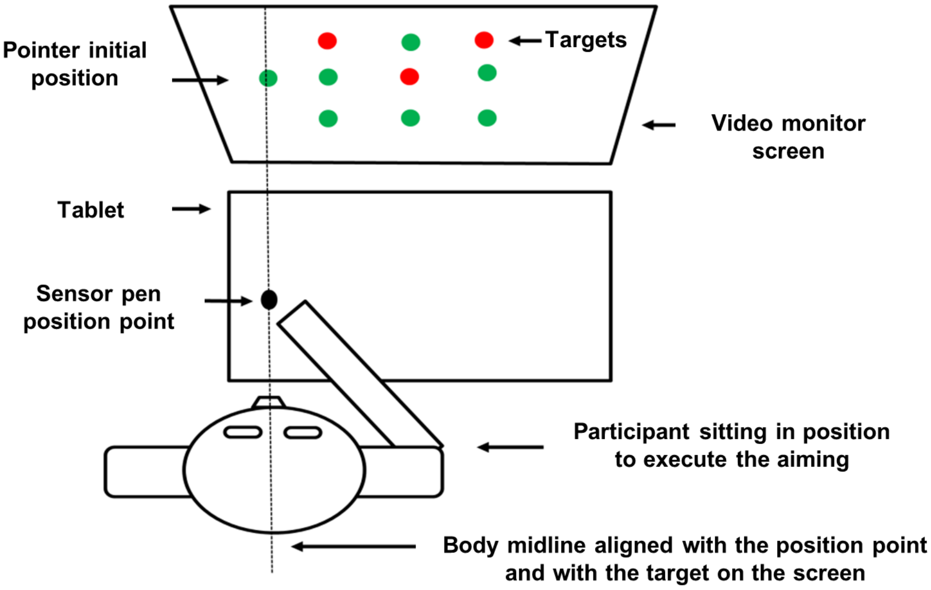

Figure 1. Top view of sitting participant and instrument position layout during collection
Source: The authors

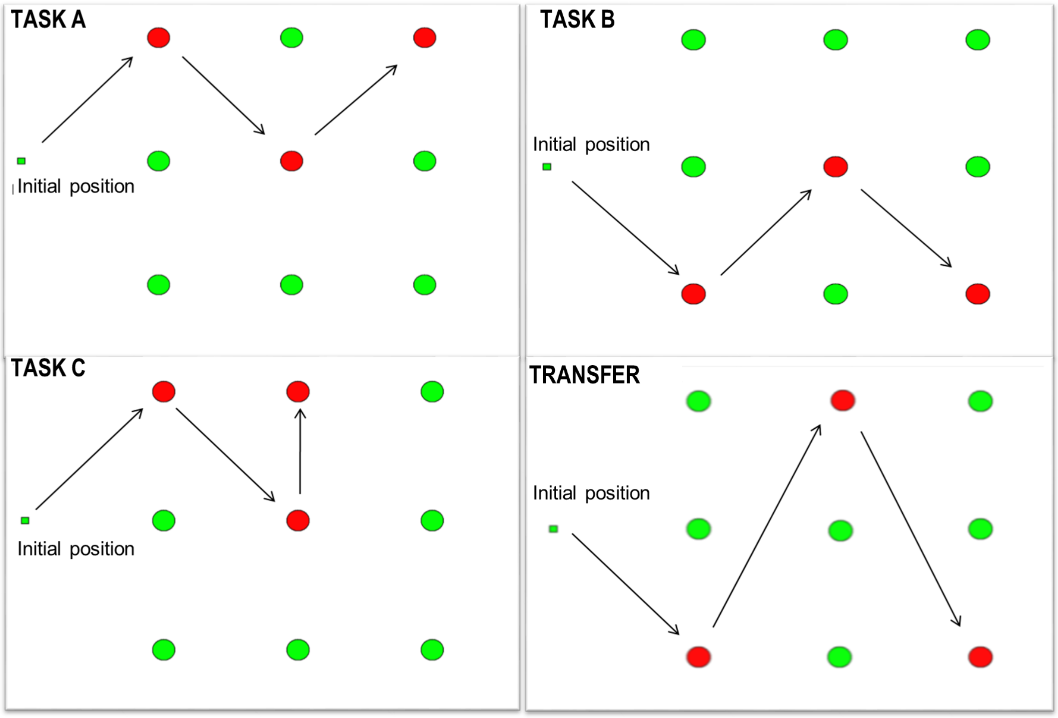

Figure 2. The three sequences required in the acquisition phase (task A, B and C) and the sequence required in the transfer test
Source: The authors

The location of the targets highlighted in the task varied in three different conditions, but the aiming sequence of the targets always followed the left-right and top-bottom or bottom-top order, thus creating an alternating movement (zigzag). The subjects should perform the task as fast and accurately as possible.

Procedures

Sitting in front of the microcomputer and the tablet, the individuals found a comfortable position, with the medial region of the body aligned with the initial point of the movement (Figure 1), and received instructions on the task. They were asked to perform the task as quickly as possible and to be precise, given that it was mandatory to hit each of the targets presented. In order to begin the task execution, the sensor pen, manipulated with the right hand, should be positioned on the starting point of the task, and only after a beep controlled by the software the trial could be initiated. To ensure that the pen was properly positioned on the starting point, a warning stimulus was visible on the screen for two seconds. In that period, the targets to be hit already indicated what sequence would be executed. This initial stimulus disappeared and within 2 to 3 seconds the sequence to be performed was displayed.

Measures adopted

Performance dependent variables were reaction time (RT), movement time (MT) and response time (respT). Kinematic dependent variables were peak velocity (PV), relative time to peak velocity (RTPV) and number of corrections to hit the target (NC). For each of the three task segments, the six dependent variables were recorded. The RT was determined as the time interval between the beeping of the sound command to start the task and the beginning of the pen displacement. MT was analyzed as the sum of the elapsed time between the beginning of the pen displacement and the hitting of the target in each segment. RespT is the sum of RT plus MT. Peak velocity refers to the highest velocity value reached during the trajectory toward the target, given in cm/sec. Relative time to peak velocity was calculated as the proportional time to reach peak velocity. The number of corrections after peak velocity to hit the target is calculated by the number of discontinuities in the acceleration profile, represented by positive and negative acceleration peaks occurring during the 2nd sub-movement, or current control phase. In tasks of aiming at multiple targets and that require change of direction, discontinuities are generated by processes of correction of the current movement and implementation of the next segment of the movement.

All performance and kinematic measures used, as well as the data filtering method, were provided by the MovAlyzer software (e.g., studies[14-16]). The movements of the pen on the tablet were filtered by a low-pass filter at 12 Hz using the Fast Fourier Transform (FFT) method and differentiated to obtain estimated velocity and acceleration curves. Each trace was segmented into primary and secondary sub-movement. The first sub-movement was the interval from the beginning of the movement until the first transition of the acceleration curve from negative to positive, or also defined as zero crossing. From this moment, the 2nd sub-movement starts. The number of corrections after peak velocity for the 1st target was calculated by the number of discontinuities in the acceleration profile, represented by positive and negative acceleration peaks that occurred during the 2nd sub-movement, or current control phase.

Analyses of online and offline learning effects were used. The difference between the performance achieved in the last block of the acquisition phase and the performance achieved in the first block of the acquisition phase is defined as online learning. This measure concerns the change process observed during practice. The difference between the performance achieved in the transfer test block and the last block of the acquisition phase is defined as offline learning. This measure concerns the process of motor memory consolidation[17]. To explain the effects of kinematic measures on performance measures, the online learning of PV, RTPV and NC measures was calculated, and the offline learning of RT, MT and respT measures was calculated as well.

Data analysis

Intra-subject performance was analyzed by mean and standard deviation in blocks of 10 trials. Six blocks were analyzed in acquisition and one block in the transfer test (TT). For each of the dependent variables, except for RT, the mean of the three sequences of the movement was calculated for each practice trial. As an example, for a given trial the mean movement time of the three trace sequences was calculated.

The Shapiro-Wilk W test was conducted to assess data normality. Normal data distribution was found for all variables. Regarding inferential analyses for the acquisition phase, a two-way ANOVA was used with repeated measures in the second factor (2 groups x 6 blocks) and, for the transfer test, Student's t-test was used. For post hoc analyses, Duncan's test was employed. Significance was set at $p < 0.05$.

Multiple linear regressions were conducted to analyze the association between kinematic measures in acquisition and the reaction time and movement time performance measures in the transfer test. Initially, Spearman correlations were conducted to assess which independent measures (RT, RTPV and NC) would participate in the regression model. Kinematic measures related to online learning were correlated with performance measures (RT, MT and respT) related to offline learning. Significance was set at $p < 0.2$. Regressions were conducted between (a) the means of online learning measures that reached significance in the correlation and (b) the means of each of the offline learning measures.

Results

Performance measures

Reaction Time

Descriptive analysis suggests that the groups started the acquisition phase with similar levels of performance (Figure 3a). The 95% confidence interval in the acquisition phase of the BPG was 0.58 to 0.61, and the RPG's was 0.51 to 0.56. In inferential analysis, the two-way ANOVA with repeated measures in the second factor did not show significant difference between Groups [F (1.20) = 1.69, $p = 0.20$, $\eta^2 = 0.07$], and no significant interaction was detected between Groups X Blocks [F (5.100) = 1.84 $p = 0.11$, $\eta^2 = 0.08$]. Difference was detected for the Blocks factor [F (5.5) = 10.07, $p < 0.001$, $\eta^2 = 0.33$]. Duncan's post hoc test indicated that the RT of the 1st block was significantly higher than the others. The RT of the 2nd block of acquisition was significantly higher than the last block of acquisition. Analyzing the transfer test block, Student's t test did not indicate a significant difference between Groups [t(20) = 1.53, $p = 0.13$, $d = 0.74$]. The 95% confidence interval in the transfer test of the BPG was 0.54 to 0.68, while the RPG's was 0.45 to 0.60.

Movement Time

Descriptive statistics are presented in figure 3b and suggest that the groups had similar performance throughout the acquisition phase. The 95% confidence interval in the BPG's acquisition phase was 2.36 to 2.62, and the RPG's was 2.36 to 2.70. In inferential statistics, the two-way ANOVA with repeated measures in the second factor did not detect significant difference between Groups [F (1.20) = 0.16, $p = 0.68$, $\eta^2 = 0.07$] and did not identify significant interaction between Groups X Blocks [F (5.100) = 1.62 p = 0.16, η² = 0.07]. Difference was detected for the Blocks factor [F (5.5) = 21.11, p <0.001, η² = 0.51]. Of the main significant differences shown by Duncan's post hoc test, it is worth noting that the RT of the 1st block, except for the 3rd block, was significantly higher than the others. Analyzing the transfer test, Student's t test indicated shorter MT for the RPG compared to the BPG [t (20) = 2.24, p <0.05, d = 0.07]. The 95% confidence interval in the BPG's transfer test was 2.89 to 3.18, and the RPG's was 2.56 to 2.95.

Response Time

Descriptive analysis is displayed in figure 3c and suggests that the groups performed similarly throughout the acquisition phase. The 95% confidence interval in the BPG's acquisition phase was 2.94 to 3.23, and the RPG's was 2.88 to 3.26. The two-way ANOVA with repeated measures in the second factor did not indicate a significant difference between Groups [F (1.20) = 0.01, p = 0.90, η² = 0.07], and no significant interaction was detected between Groups X Blocks [F (5.100) = 1.82 p = 0.11, η² = 0.08]. Difference was detected for the Blocks factor [F (5.5) = 24.75, p <0.001, η² = 0.55]. In the transfer test block analysis, Student's t Test indicated lower respT for the RPG compared to the BPG [t (20) = 2.63, p <0.05, d = 0.02]. The 95% confidence interval in the BPG's transfer test was 3.46 to 3.82, and the RPG's was 3.09 to 3.48.

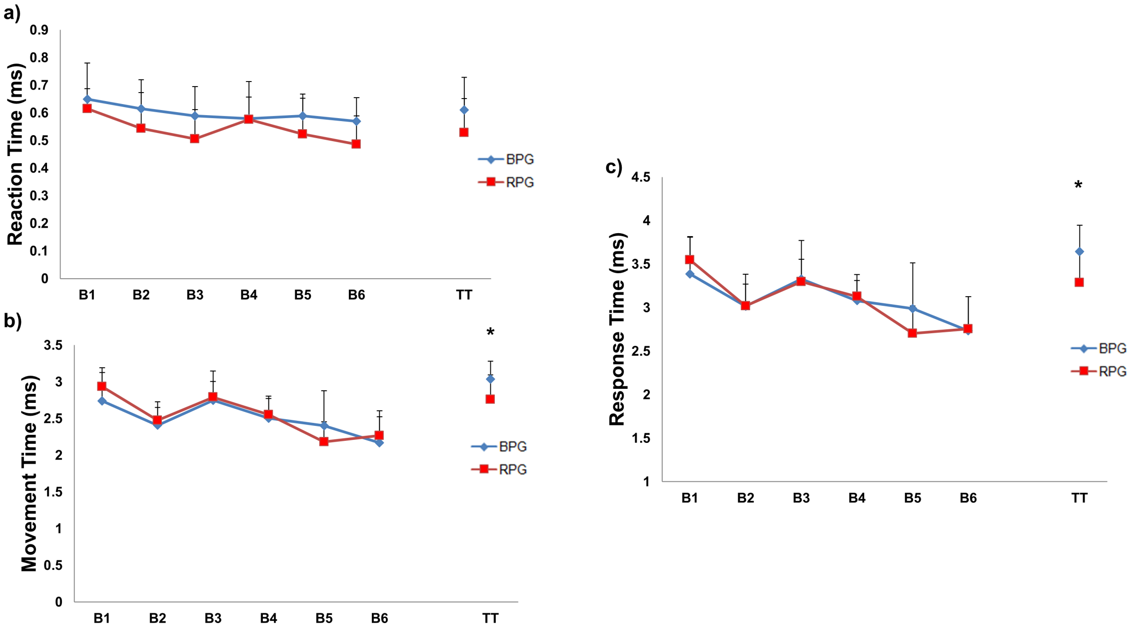

Figure 3. Mean and standard deviation of performance measures
Legend: BPG = Blocked Practice Group; RPG = Random Practice Group; B1 ... B6 = mean and standard deviation of the 11 participants in 6 blocks of 10 trials each; TT = transfer test, and * p <0.05
Source: The authors

Kinematic Measures

Peak Velocity

Descriptive analysis suggests that the groups performed similarly throughout the acquisition phase (Figure 4a). The 95% confidence interval in the BPG's acquisition phase was 18.61 to 20.16, and the RPG's was 19.28 to 21.46. The two-way ANOVA with repeated measures in the second factor showed no significant difference between Groups [F (1.20) = 0.44, p = 0.51, η² = 0.02] and did not detect significant interaction between Groups X Blocks

[F (5.100) = 1.38 $p = 0.23$, $\eta^2 = 0.06$]. Difference was detected for the Blocks factor [F (5.5) = 12.11, $p < 0.001$, $\eta^2 = 0.37$]. Among the main findings, Duncan's post-hoc test stands out, indicating that 1st block PV, except for the 3rd block, was significantly lower than the others. In the transfer test analysis, Student's t test did not indicate a significant difference between Groups [t (20) = -1.73, $p = 0.09$, $d = 0.31$]. The 95% confidence interval in the BPG's transfer test was 23.18 to 29.26, and the RPG's was 26.75 to 34.18.

Relative Time to Peak Velocity

Descriptive analysis is presented in Figure 4b and suggests that the BPG showed higher RTPV throughout the acquisition phase. The 95% confidence interval in the BPG's acquisition phase was 40.17 to 42.64, and the RPG's was 41.25 to 41.30. In the inferential analysis, the two-way ANOVA with repeated measures in the second factor did not indicate significant difference between Groups [F (1.20) = 1.01, $p = 0.32$, $\eta^2 = 0.04$], and no significant interaction was detected between Groups X Blocks [F (5.100) = 1.97 $p = 0.23$, $\eta^2 = 0.06$]. Difference was detected for the Blocks factor [F (5.5) = 12.11, $p < 0.001$, $\eta^2 = 0.37$]. Among the main findings, Duncan's post-hoc test stands out, showing that the 1st block RTPV, except for the 3rd block, was significantly shorter than the others. Analyzing the transfer test block, Student's t test did not indicate significant difference between Groups [t (20) = -0.32, $p = 0.75$, $d = 0.38$]. The 95% confidence interval in the BPG's transfer test was 40.65 to 40.70, and the RPG's was 41.25 to 41.30.

Number of Corrections

Descriptive statistics suggest that the groups showed similar behavior throughout the acquisition phase (Figure 4c). The 95% confidence interval in the BPG's acquisition phase was 7.29 to 8.51, and the RPG's was 6.77 to 8.03. In the inferential statistics, the two-way ANOVA with repeated measures in the second factor did not detect significant difference between Groups [F (1.20) = 0.45, $p = 0.50$, $\eta^2 = 0.02$] and did not detect significant interaction between Groups X Blocks [F (5.100) = 1.11, $p = 0.23$, $\eta^2 = 0.06$]. Difference was detected for the Blocks factor [F (5.5) = 21.60, $p < 0.001$, $\eta^2 = 0.51$]. Among the main findings, Duncan's post-hoc test stands out, showing that the 1st block NC was significantly lower than the others. Analyzing the transfer test block, Student's t test did not indicate significant difference between groups [t (20) = 1.14, $p = 0.26$), $d = 0.23$]. The 95% confidence interval in the BPG's transfer test was 8.00 to 11.18, and the RPG's was 6.91 to 9.77.

Multiple Linear Regressions

Correlation analyses between online learning measures and offline learning measures indicated that only the correlation between the online learning measure of PV ($r = 0.61$, $p = 0.04$) correlated significantly with the offline learning measure of RT. Thus, a simple linear regression analysis was conducted and showed significant association [F (1.9) = 5.40, $p = 0.04$, $r^2 = 0.30$] between the measure related to PV change in the acquisition phase and the measure related to RT change from the end of acquisition to transfer test [B = 0.61].

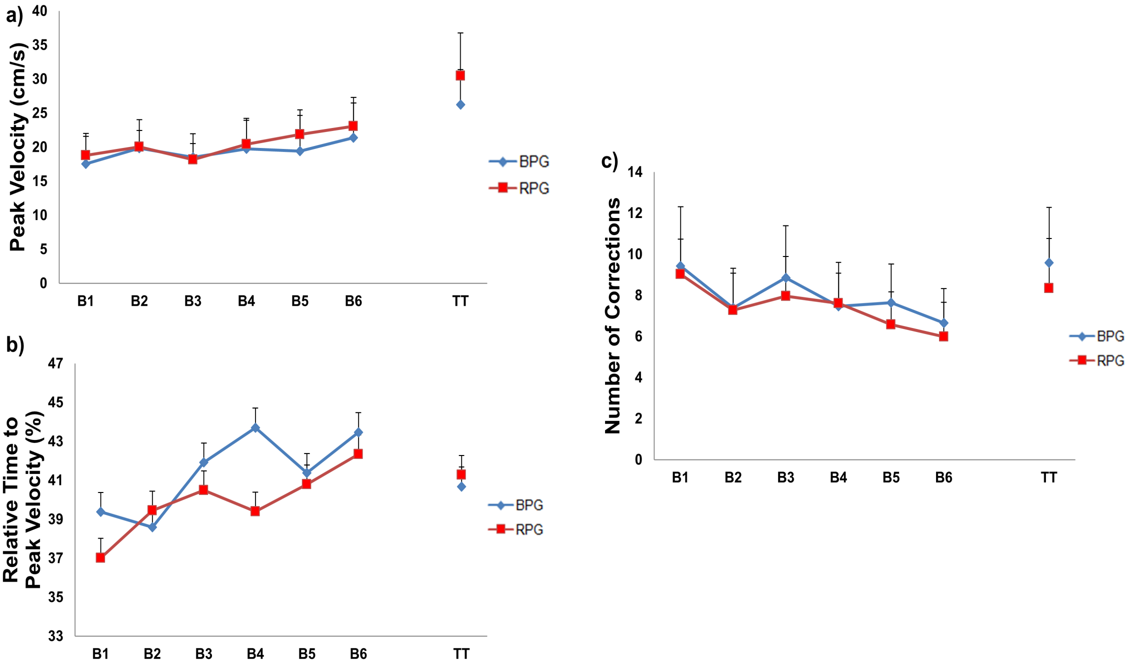

Figure 4. Mean and standard deviation of kinematic measures
Legend: BPG = Blocked Practice Group; RPG = Random Practice Group; B1 ... B6 = mean and standard deviation of the 11 participants in 6 blocks of 10 trials each, and TT = transfer test
Source: The authors

Discussion

The objective of the present study was to investigate the effect of contextual interference on the velocity and acceleration kinematic profiles of the upper limb. Although differences between the practice groups were not observed in the acquisition phase for any of the measures assessed, the transfer test results showed contextual interference effect for movement time and response time measures. That is, the random practice group performed better as to these variables compared to the blocked practice group. Regarding the kinematic analyses, no difference was found between groups for any of the measures used. However, it was observed that peak velocity online learning is associated with the offline change in reaction time only in the random practice group.

Analyzing the performance of practice groups during the acquisition phase in CIE studies, differences between groups is frequently not observed[18]. It is expected that the random practice group performs worse during practice, considering that variations occurring trial after trial lead to a higher level of interference, generating a higher level of error[1]. However, it is important to consider that CIE results from differences in type of processing required throughout practice and that it is possible to observe similar performances that are generated by different levels or processing types[4,19].

A result that strengthens the hypothesis that distinct processes occurred between practice groups is found in the regression analysis. The change observed from the beginning to the end of the practice in the peak velocity measure (online learning) as to the random practice group had a significant impact on the change observed in the reaction time between the end of the practice and the transfer test (offline learning). The same was not found analyzing the blocked practice group. Peak velocity is a measure associated with the central control phase, that is, the preprogrammed phase of the action[9]. Random practice requires the reconstruction of the action plan with each new practice trial[20,21]. Bearing in mind that one of the task's goals is velocity, it is possible that this is the main parameter to be programmed during the trials. As this process of reconstructing the action plan is less required during blocked practice, it seems that peak velocity did not present the same level of association with the reaction time measure in the more repetitive practice compared to the less repetitive one. A strategy used by individuals to improve performance in the manual task used in the studies by Lin et al.[22,23], which confirmed CIE, was to emphasize improvement in time-related variables. Transfer seems to be an accelerated form of learning in which processes experienced during acquisition are superimposed on those required in a near condition in the learning test[12]. Future studies need to be conducted to investigate this hypothesis that in random practice the main parameter programmed in the acquisition phase, and that impacts transfer, is peak velocity.

No difference was found between groups as to relative time to peak velocity. This result indicates that both groups presented a similar motor control strategy. Both in acquisition phase and transfer test, the groups had a higher percentage of time in the current control phase, evidencing a strong dependence on the use of feedback to try to hit the targets with precision[7,24]. The groups presented a range of 60 to 65% of the time in the current control phase. Compared to studies that used a similar task, but with the requirement of discrete movements (displacement to a single target), this range was below the one previously observed[9,25]. The second sub-movement is affected in aiming tasks with changes of direction[7]. In the present study, the higher percentage of time spent in the current control phase, compared to studies with discrete aiming movements, is explained by the overlap of processes related to the correction of errors in the segment being executed and to the implementation of the next task segment. This overlap leads to an increase in time in the final phase of the movement[7]. Another result that reinforces the proposition that the strategy of both groups was based predominantly on current control is the average number of corrections. Because the participant had to hit all targets, besides the corrections to hit the targets a behavior observed during the data collection was the production of reverse movements back to the target that was overpassed, but not hit.

Conclusion

Contextual interference effect was found in movement time and response time measures. The random practice group performed better as to these two dependent variables in the transfer test. High contextual interference leads to greater strengthening of active processes due to complete or partial forgetfulness that forces the learner to reconstruct his action plan with each new practice trial[18]. This strengthening of active processes was observed in the transfer test, when the random practice group managed to be faster than the blocked practice group, meeting the task goal, which was to execute as quickly as possible. No differences were observed between groups in the kinematic measures analysis. However, the regression analysis showed that the changes generated in peak velocity, when practiced randomly, impact the reaction time in a new practice condition. Altogether, these results reinforce the hypothesis that distinct processes occurred between the practice groups and that peak velocity is the kinematic measure that most impacts the observed performance. However, further studies need to be conducted to investigate the possibility of velocity being the main parameter to be programmed during trials in sequential tasks that require velocity and precision.

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