



Effects of the different distributed practice regimes on the learning of three-ball cascade juggling task

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ABBREVIATIONS

AMONG Among days distributed practice group
MASSED Massed practice group
WITHIN Within-one-day distributed practice group

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BACKGROUND: In its majority, the literature supports the superiority of distributed practice compared to massed practice on motor learning outcomes. However, inconsistencies in some findings claim for more efforts on this topic.

AIM: We aimed to elucidate potential mechanisms that would support the distinct results between the different distributed practice regimes (among days and within-one-day).

METHOD: Ninety participants, aged 18-25 years (45 men, 45 women) were randomly divided into 3 groups: Massed practice group (MASSED) - 30 minutes of practice without rest/ one day; Within-one-day distributed practice group (WITHIN) - 6 blocks of 5 minutes of practice interspersed by 3 minutes of rest/ one day; and, Among days distributed practice group (AMONG) - 3 blocks of 10 minutes of practice divided into 3 consecutive days. They practiced the three-ball cascade juggling task. The number of catches was the dependent variable. There was a retention test (absolute retention and savings analyses) after 24 hours from the acquisition phase.

RESULTS: We identified that AMONG demonstrated higher absolute retention than WITHIN and MASSED. Both distributed practice regimes demonstrated better savings than MASSED.

CONCLUSION: Our results showed that distributed practice regimes enhance consolidation processes and information processing that benefit motor learning.

KEYWORDS: Practice distribution | Motor learning | Information processing | Consolidation | Savings

INTRODUCTION

Distributed practice refers to the spacing of practice over multiple sessions instead of compacting practice time into a smaller number of sessions (massed practice)¹. The terms massed and distributed are defined in a continuum; typically, a massed practice schedule involves longer active practice and shorter rest periods (or even without rest) in comparison to a distributed schedule².

Several studies have demonstrated that when practice amount is paired, distributed practice tends to induce better motor performance and learning than massed practice condition³. Interestingly, the superiority of the distributed practice compared to massed practice has been reported in schedules in which practice is distributed *within* a practice session (i.e., 30 minutes of massed practice versus 3 blocks of 10 minutes of practice interspersed by 5 minutes of rest)⁴⁻⁶; and in distributed practice *among* days (i.e., 30 minutes of massed practice versus 3 blocks of 10 minutes of practice interspersed into 3 consecutive days)⁷⁻⁹. In contrast, some authors attribute the inferiority of massed practice in comparison to distributed practice only for motor performance instead of motor learning outcomes (i.e., retention and transfer tests)¹⁰⁻¹². Yet, Lee and Genovese^{13,14} identified that the distribution of practice enhances the learning of continuous motor skills,

while massed practice schedules benefit the learning of discrete motor skills.

Despite these controversies, scientific literature generally attributes better motor learning for distributed practice schedules. From a mechanistic perspective, it has been suggested that distributed practice benefits motor learning by decreasing the deleterious effect from fatigue, by increasing cognitive effort avoiding monotony and excessive repetition, and by improving memory consolidation stimulating this mechanism across several days (for the among days distributed practice)².

The plausibility of all these mechanisms in explaining the effects of distributed practice can be reexamined given that: 1 - even with fatigue the motor learning occurs¹⁵, 2 - distributed practice does not necessarily engage a higher cognitive effort without some attention direction, as visual instructions^{1, 3} - motor memory consolidation is not necessarily sleep-dependent (which would explain effects from distributed practice among days). It has been suggested that motor memory consolidation also occurs during wakefulness periods that are temporally close to practice¹⁶.

From these inconsistencies regarding the mechanisms involved in the superiority of distributed practice compared to massed practice during motor learning, we seek to explore whether the different regimes of distribution of practice (within-one-day and among days) have different effects on motor learning. Given that possibly among days distributed practice would influence motor learning through different mechanisms (motor memory consolidation) if compared to within-one-day distributed practice. Some motor tasks demonstrate to be more sensitive for sleep-dependent consolidation, while others seem to have the consolidation process independent from sleep¹⁷. In our study, we used a three-ball cascade juggling task that appears to have consolidation based on a sleep-dependent mechanism^{18,19}.

Based on three different practice regimes (massed practice, within-one-day distributed practice, and among days distributed practice), we hypothesized the following scenarios: In case of fatigue or cognitive effort is the main mechanism involved in distributed practice phenomenon, both distributed practice regimes (within-one-day and among-days) would demonstrate better retention than massed practice, without differences between them; but, if consolidation is the main mechanism that benefits distributed practice, among-days distributed practice would induce better retention than within-one-day distributed practice and massed practice; however, if sleep, fatigue, and cognitive effort have complementary effects on motor learning, both distributed practices would demonstrate better retention than massed practice, but among-days distributed practice would demonstrate superior retention than within-one-day distributed practice. To the best of our knowledge, this is the first study investigating the effect of practice distribution comparing the three distribution regimes (massed, within-one-day, and among days).

METHODS

The ethics board from the State University of Piauí approved this study (protocol number. 30456820.0.0000.5209). All participants signed the consent term before participation. There was no compensation to participate in this study. All experiment was conducted following Helsinki Declaration.

Participants

We used the power analysis software G*Power 3.1²⁰ to determine the sample size. Estimating an effect size of 0.66 (based on the performance difference across the practice in Morita et al.¹⁸), $\alpha = 0.05$, and a power of 0.8 indicated a sample size of 26 per group.

We recruited 90 naïve participants from the local university community, aged 18-25 years (21.62 ± 2.09); 45 men, 45 women. The inclusion criteria were: 1 – To be a university student. We adopted the following exclusion criteria: 1 – To have cardiovascular or osteoarticular diseases or disfunction which unviabile the performance of the proposed activities; 2 – Do not have visual, neuromotor and cognitive conditions for understanding and executing the proposed tasks; 3 - Do not use a corrective lens in case the participant has unsatisfactory visual acuity; 4 – To have previous experience in juggling tasks.

Apparatus and Task

We used three plastic balls with 76mm of diameter and mass of 160g for the juggling task. As Morita et al.¹⁸ performed in their study, participants threw the first ball from the right to the left hand (the first catch). The second ball was thrown from the left to the right hand (the second catch), then, if participants were able, the third ball was thrown from the right to the left hand (the third catch). In this way, the task goal was to perform as many catches as possible per trial without letting balls fall to the ground. When participants failed to catch the balls, the experimenter delivered extra balls immediately to avoid delay in restarting the subsequent trial. The dependent variable was the number of catches per trial from the second catch. Thus, whether the participant performed five catches, we computed three catches.

Procedure

After participants signed the consent form, they were divided into three groups through a stratified random process considering sex: Massed Group (MASSED) ($n = 30$), which completed the acquisition phase without rest (30 minutes of practice without rest/ one day); Within-one-day Distributed Practice (WITHIN) ($n = 30$), which had rest cycles during the practice (6 x 5 minutes of practice interspersed by 3 minutes of rest/ one day); and Among Days Distributed Practice (AMONG) ($n = 30$), (3 x 10 minutes of practice divided into 3 consecutive days).

At the beginning of the experiment, each participant received an instructional video about the motor pattern to perform the task. From the front view, the instructional video demonstrated an experienced model performing the three-ball cascade juggling task for 1 minute. The experient model performed 162 uninterrupted catches during the video.

After, participants were verbally instructed to initiate holding 2 balls in the right hand, given that the first thrown should be performed from the right to the left hand. All participants watched the same video and received the same verbal instruction. Then, participants performed three trials as familiarization. They completed a pre-test consisting of five trials (the duration of each trial depended on the number of catches that each participant was able to achieve). After the pre-test, participants practiced the task for 30 minutes in the specific condition of their respective group (MASSED, WITHIN, or AMONG). After the last trial of the acquisition phase, participants rested for 2 minutes, and then they performed a post-test with the same pre-test characteristics.

After 24 hours from the post-test, participants completed a retention test with the

same pre-test and post-test characteristics. Following, participants of all groups completed 30 minutes of massed practice to verify whether they demonstrated savings.

Statistical Analyses

We used STATISTICA 11.0 (StatSoft Inc., Tulsa, OK, USA) and Microsoft Excel 365 softwares for statistical analyses adopting a 5% significance level. We evaluated the normality and homogeneity of the data with the Shapiro Wilks and Levene tests, respectively.

We assessed the motor performance changes using the mean of catches in each block of trial (pre-test, post-test, and retention test). As inferential analyses, we performed an ANOVA two-way - 3 groups (MASSED, WITHIN, AMONG) x 3 times (pre-test, post-test, retention test) with repeated measures in the second factor. Fisher test was used for post hoc analyses.

As Schmidt et al. ²¹ stated, savings is a measure of retention which involves the rate of relearning; “that is, after a retention interval, one measures the number of trials required for the participants to reach the level of proficiency achieved in original practice”. We evaluated savings by computing the number of trials (on the second day) required for participants to reach the mean performance achieved in the post-test. Then, we verified the effects of the practice distribution on savings, comparing the number of trials among MASSED, WITHIN, and AMONG through an ANOVA one-way with a Fisher post hoc test. We reported Cohen’s *d* as an estimate for effect sizes.

RESULTS

Considering the mean of catches during acquisition phase and retention test, we identified an interaction effect in the ANOVA two-way ($F_{2,87} = 5.86, p < .0001, d = .66$). The Fisher post hoc test demonstrated that there was no difference among groups in pre-test and post-test, and all of them improved their performance comparing pre-test and post-test (MASSED, $p < .0001$; WITHIN, $p < .0001$; AMONG, $p < .0001$). There was no significant difference between post-test and retention test for all groups (MASSED, $p = .17$; WITHIN, $p = .22$; AMONG, $p = .76$), which indicates that all groups learned the juggling task. However, AMONG demonstrated significant difference in retention test if compared to MASSED ($p = .01$) and WITHIN ($p = .01$); there were no significant difference between MASSED and WITHIN in retention test ($p = .89$). These results can be checked in Figure 1.

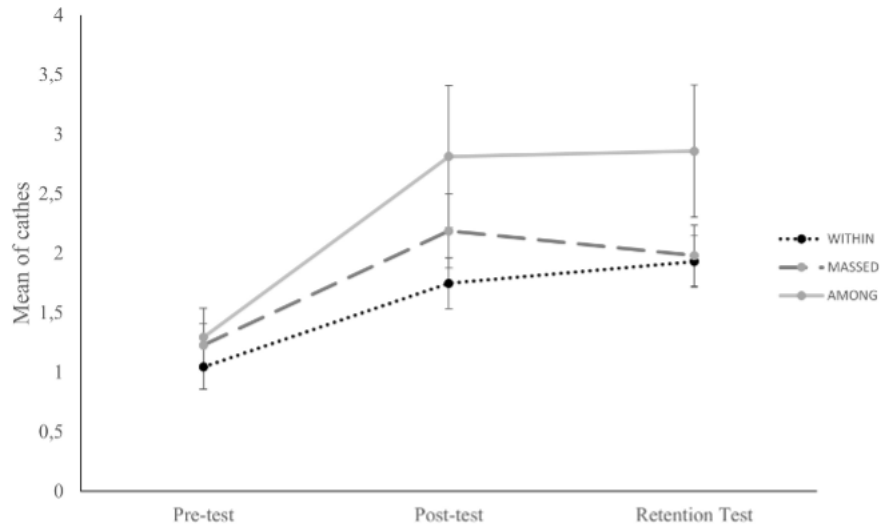


Figure 1. Mean of catches for WITHIN, MASSED, and AMONG across acquisition phase and retention. Data represent mean and confidence interval 95%.

In our savings analysis, the ANOVA one-way demonstrated a significance in group factor ($F_{2,87} = 3.59, p < .05, d = .6$). The Fisher post hoc test demonstrated a significant difference between AMONG and MASSED ($p = .01$) and WITHIN and MASSED ($p < .05$). Interestingly, there was no significant difference between AMONG and WITHIN ($p = .89$). In this way, it is possible to verify that AMONG and WITHIN needed fewer trials in savings to achieve the mean performance of the post-test than MASSED. These findings can be verified in Figure 2.

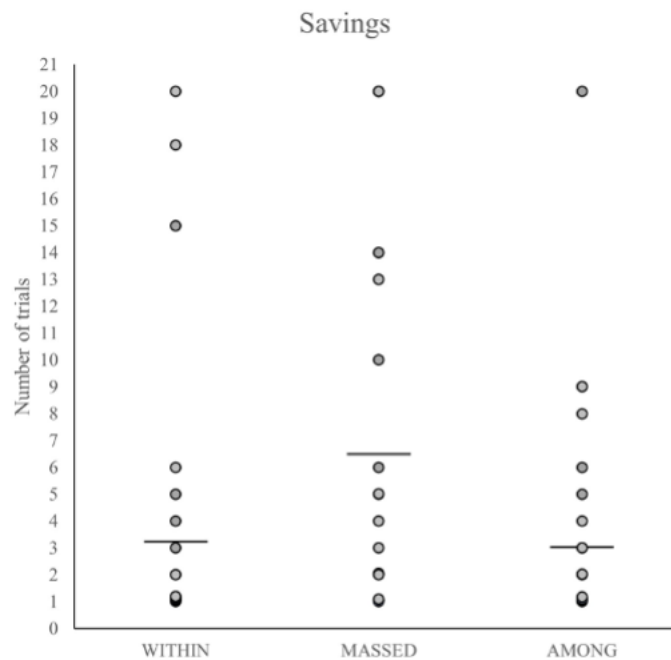


Figure 2. Blocks of trials on day 2 to achieve the post-test mean performance. Data show the mean of blocks in each group (solid line) and individual data (dots)

DISCUSSION

We aimed to investigate the effects of two different distributions of practice (within-one-day and among days) in motor learning. Based on possible mechanisms that these different practice distributions could engage, we hypothesized that they could affect motor learning differently. The literature has attributed for the distributed practice the higher engagement for cognitive processing and lower monotony, as well it has been postulated that among-days distributed practice engages more consolidation mechanisms which could induce better retention². Our findings support the previously mentioned mechanisms. We found that among-days distributed practice influenced consolidation mechanisms that allow better absolute retention (first trials of a retention test) than within-one-day distributed practice and massed practice. However, both distributed regimes demonstrated faster savings than massed practice, without differences between them.

Practice distribution can be considered as one of the classic themes in the motor learning field. Previous studies have already demonstrated the superiority of distributed practice compared to massed practice⁴⁻⁹. However, part of the literature advocates that distributed practice has little or no effect on learning and concludes that massing of practice impairs just motor performance instead of any permanent decremental states (motor learning)¹⁰⁻¹². Based on our experimental design, we can suppose the mechanisms involved in the superiority of distributed practice regimes compared to massed practice: motor memory consolidation and higher cognitive engagement.

Consolidation is the post-practice phase when the memory becomes more robust and stable with less susceptibility to interference^{22,23}. Our results corroborate the hypothesis that among days distributed practice can impact motor learning enhancing consolidation processes. Given that, the maintenance of improved performance in absolute retention (first trials of a retention test) reveals the effectiveness of a consolidation process of a particular motor memory²⁴. So, we attributed the fact that AMONG had superior absolute retention than WITHIN and MASSED by the prolonged influence of this practice distribution on consolidation processes. Due to the AMONG regime, the participants had a multi-day consolidation process (3 consecutive days of sleep-dependent consolidation) that did not occur in WITHIN or MASSED participants, with only 1 sleep-dependent consolidation event.

Several findings suggest that motor memory consolidation occurs temporally close to practice (in wakefulness) and during sleep¹⁶. Additionally, the participation of sleep-dependent or wakefulness-dependent consolidation processes seems to differ according to the task nature or demand²³. For example, it has been suggested that movement components have consolidation processes during wakefulness, while the goal component of the motor skill is consolidated in a sleep-dependent condition²³. Thus, the influence of the within-one-day distributed practice on consolidation may depend on whether the task to be learned had the consolidation process engaged in a wakefulness-dependent condition. In our case, the juggling task seems to have the consolidation process in a sleep-dependent condition¹⁸, which explains the superiority of the AMONG in the absolute retention in our study.

In fact, the interaction between distribution practice regime, type of motor task and consolidation mechanisms (sleep-dependent or wakefulness-dependent) may explain that in some cases, the distributed practice did not demonstrate superiority to massed practice

^{3,13}. The literature has been attributed this inconsistency to task nature (continuous or discrete) ^{8,14}. But, maybe the task nature interacts with the consolidation mechanism in the distribution practice effects. The interaction between distribution practice regime and type of motor task in a motor memory consolidation scope can be an interesting issue for further investigations.

Our findings also suggested that distributed practice (independently of the regime) contributes to information processing that subsidizes motor improvement during practice and relearning. This finding corroborates the perspective that a higher cognitive effort can be induced by distributed practice given the monotony break ². Our results demonstrated that both distributed practice regimes induced better savings than massed practice. Savings analyses provide information about the processing structure learned in a previous practice, which allows a faster-relearning rate. Thus, we suppose that distributed practice benefits this processing structure, influencing motor skills acquisition.

Interestingly, we identified that the improved processing structure provided by the distributed practice could not be attributed to decreasing fatigue by the rest. Because we did not identify significant differences among WITHIN, AMONG, and MASSED in post-test. Previous findings demonstrated that moderate fatigue (as induced by massed practice schedules) impairs motor performance, but not motor learning ^{15,25}. Then, we suppose that the enhancement of the processing structure identified in distributed practice regimes can be derived for a higher engagement instead of simply avoiding fatigue's detrimental effect.

Finally, we mentioned sleep-dependent consolidation and higher cognitive engagement as possible mechanisms involved in the superiority of the distributed practice on massed practice; however, we did not have measures about these mechanisms, which can be interpreted as a limitation. Further investigation could address it with brain activity assessment as electroencephalogram and polysomnography, providing a better understanding of practice distribution effects on motor memory consolidation and higher cognitive engagement.

CONCLUSION

Therefore, we conclude that the distributed practice regimes impact motor learning positively. The possible mechanisms involved could be the enhancement of motor memory consolidation processes and increasing cognitive engagement. For motor memory consolidation enhancement, the distributed practice needs to spread in a convergence with the temporal scale that motor memory consolidation occurs (wakefulness or sleep).

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