DISTRIBUTION OF PRACTICE EFFECTS ON OLDER AND YOUNGER ADULTS' MOTOR-SKILL LEARNING ABILITY

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ABSTRACT

Purpose. In this study, we investigated the effects of the distribution of practice (distributed vs. massed) on the learning of a coincident timing task by young and older adults. **Methods.** Sixteen young adults and sixteen older adults were subdivided into distributed and massed practice groups. The participants completed a coincident timing task that consisted in touching five sensors in sequence under a time constraint in two learning phases: acquisition and transfer. **Results.** There were no performance differences between the groups in the acquisition phase. However, older adults in the massed practice group featured the poorest performance in the transfer test. No differences were found among the other groups. **Conclusions.** Older adults are more receptive to distribution practice as massed practice was found to lead to poorer learning. Comparisons of learning effectiveness between young and older adults are dependent on the adopted intra-session intervals. In addition, the conflicting results on distribution of practice may be related to subject–task interactions.

Key words: massed practice, distributed practice, spaced practice, motor learning, timing task

Introduction

The distribution of practice refers to the relationship between the time effectively spent on performing a task (i.e. all trials of the task) and the time spent resting, either within a single practice session or between several practice sessions [1–3]. A single practice session may be classified as either massed or distributed based on the rest intervals observed among the trials within the entire session (i.e. inter-trial intervals) [3–5]. Mass practice is when the total time spent executing the task is superior to the total inter-trial interval and, reversely, distributed practice if the sum of all the inter-trial intervals is larger to the total time spent executing the task [4].

The distribution of practice was extensively studied in the 1950s and 1960s (see [3] for review), a period in which motor behavior studies focused on the effects of practice upon learning and performance. Nevertheless, a number of aspects surrounding this topic still remain unanswered; although studies have indicated some effects of distribution, many of the results are conflicting [1, 6–9]. One of these aspects relate to the effects of distribution of practice on older adults, since almost all studies have been conducted with only young adults.

Older adults generally present poorer performance than younger adults [10, 11], and many biological changes such as the functional deregulation of the motor cortex [12], a breakdown of myelin sheaths and a reduction

in neurotransmission [13] may account for reduced sensory-motor capacity and degraded performance. As a result of these changes, one could infer that aging could lead to impairment of not only performance but motor learning as well. However, it has been found that, despite the decrement in performance, older adults maintain learning capacity [14, 15], although controversy still exists on how well it is preserved. It has been shown that older adults may present either deteriorated [16] or similar learning results [17] compared with young adults.

Bock & Schneider [14] posit that this controversy may be caused by the absence of controlled or standardized rest intervals. In fact, only Buch et al. [16] mention the use of rest intervals, although no precise definition was provided: "brief rest periods were allowed as needed…" [16, p. 61]. The significance of inter-trial intervals is that they are used for information processing [4, 18], suggesting that the longer the interval the better the possibility to process information. If it is considered that aging reduces information processing speed [12, 19], one could expect that a practice schedule with longer intervals would enable a better learning response from older adults by facilitating information about each trial of the task processed after every execution [4, 18]. Therefore, we aimed to investigate the effects of inter-trial distribution upon the learning of a complex serial coincident timing task by both young and older adults. Timing tasks are characterized by coinciding spatial and temporal elements of task execution to an external event, such as when a tennis player prepares to use a forehand stroke as well as suitably positions the body, i.e. the tasks, in order to successfully

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return the ball. This occurs all the while the player visually follows the approach of the ball and has to complete the task in the exact space and time frame of the ball.

The complex timing task used in this study had been previously used by this research team [20, 21]. The serial nature of the task provides a more complex environment than a discrete task [4] and was considered to be best suited to test the study hypothesis as it could more significantly load the information processing system. In addition, the imposed temporal constraint requires a participant to successfully organize task components in order to accomplish their goal [21].

We hypothesized that the use of distributed practice ought to enable older adults to learn better than when subjected to a massed schedule due to the longer inter-trial intervals, which would allow the subjects more time to process information. Inversely, the use of shorter inter-trial intervals (i.e. massed practice) ought to feature deteriorated learning ability, especially in the case when comparing older adults with young adults, due to the lack of time to process information.

Material and methods

Thirty-two participants, of which 16 were young adults, six men and ten women aged 19 to 27 years (22.5 ± 2.43 yrs), and 16 were older adults, five men and eleven women aged 62 to 74 years (66.9 ± 4.36 yrs), volunteered to participate in the study although naïve to the task and true purpose of the experiment. The young adults were university students while the older ones were involved in physical activity programs. All participants were right handed and reported normal or corrected-to-normal vision. Prior to data collection, the participants read and signed an informed consent form in accordance to the University Ethics Committee in Research Involving Human Subjects (ETIC 509/07).

The apparatus had been used in previous studies [20, 21] and consisted of a stimulus array 1.83m in length containing 97 light-emitting diodes (LEDs) aligned in a column. The first LED on the top of the array was yellow (warning LED) and the other 96 were red. The stimulus array was placed upon a table in front of the subject at a 30° inclination from the horizontal plane. Connected to this array was a response box that housed six photoelectric sensors (each 0.11 m × 0.11 m) numbered 0 to 5. The array and response box were connected to a computer for programming and data recording (see Fig. 1), with all data collected and registered by software specially designed to operate and integrate the stimulus array and the response box with a temporal precision of 1 ms.

To begin the task, the participant positioned his/her right hand on sensor 0 and the topmost yellow LED on the stimulus array was turned on to focus the participant's sight towards the top of the array. After a small interval (~1 s) the yellow LED was extinguished and
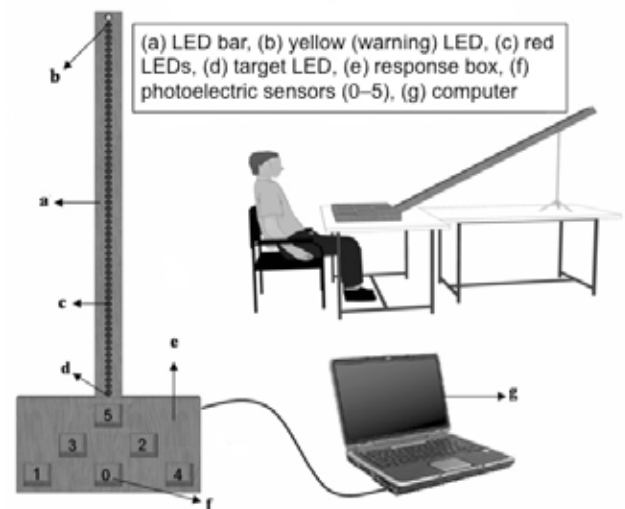

Figure 1. Experimental setup for task execution

the red LEDs were lit in sequence simulating an object 'rolling' down the array towards the response box at a constant speed of 0.45 m/s, with the total sequence lasting 4000 ms. The aim of the task was for the subject to touch the other photoelectric sensors in sequence, from 1 to 5, as shown in Figure 1, however fast they wanted with two imposed constraints: (1) to touch sensor 5 at the very instant the last red (target) LED was lit and (2) once participants started the exercise they could not stop until touching all five sensors. They were informed that they could regulate the speed at which they touched the sensors (i.e. accelerate or decelerate) to accommodate the speed of the LEDs but they could not stop. The second constraint was established to ensure that the participants would not touch sensors 1 to 4 as rapidly as possible and then wait to touch sensor 5 as this would invalidate the serial nature of the task.

Considering that older adults are more likely to present a variety of cognitive dysfunctions, the Portuguese mini-mental state questionnaire [22] was completed by the participants. This was done to ensure whether any poor results were the result of learning the task and not misunderstanding the instructions or the task itself. In addition, the participants were familiarized with the equipment in order to ensure that none, especially the older adults, featured any biomechanical or pathological conditions that could prevent them from fully completing the task as well as guaranteeing that all started off with the same level of experience. In this regard, ten executions of the task were performed at maximum speed, and the participants were encouraged to mention any pain or discomfort different from that experienced during activities of daily living, in which case the volunteer would be dismissed. These ten pre-trials were also used to regulate the chair height and distance from the response box for each participant. The participants also received standardized instructions and their understanding was checked by asking them to repeat what was expected of them; data acqui-

Table 1. Participants' age and group distribution

	Young		Older	
	M	D	M	D
Age (m ± sd)	22.4 ± 3.1	23.3 ± 1.5	68.3 ± 4.7	65.6 ± 3.8
Men (*n*)	3	3	2	3
Women (*n*)	5	5	6	5

Mean age with standard deviation; M – massed; D – distributed

sition began only when the participant clearly understood the instructions.

The participants were randomly separated into four experimental groups: two composed of young adults under a massed (youth-massed: YM) and distributed (youth-distributed: YD) practice schedule, and two groups of older adults under a massed (older-massed: OM) and distributed (older-distributed: OD) practice schedule; each group was composed of eight individuals of both sex (Tab. 1).

The experiment was divided into two phases: skill acquisition and transfer. During the acquisition phase the participant had to meet a criterion level of three trials in a row with error (more information on error is provided further below) equal or smaller than 30 ms in up to 297 trials. This criterion was adopted in an attempt to identify performance stabilization in this task (i.e. high scores with low variability) and enable a more reliable comparison of learning. If individuals have a different rhythm of learning and have the same amount of practice, this practice may represent different levels of competence among the subjects. With our criterion level procedure, all of the subjects have achieved a minimum degree of competence that could be then analyzed. This methodological strategy had already been applied in other studies [20, 21].

The distribution of practice was conducted in accordance to the group they were assigned to. The YM and OM groups performed the trials with a 3-s inter-trial interval until the criterion level, described above, was met. Three seconds was the shortest possible time that could be allowed between trials but was short enough to keep the interval/performance ratio within the range proposed in massed practice [4]. Groups YD and OD performed the task in blocks of nine trials with an interval of about 40s between blocks besides the inter-trial interval of 3 s, performed until the criterion level was achieved.

During the acquisition phase the researcher monitoring the experiment provided qualitative knowledge of results (KR) after each trial. The feedback provided by the researcher was determined as the difference between the response time and target time, where the word "slow" was used when the participant finished the trial after the last red LED had lit up and "fast" was used in those trials that were finished before the last LED had turned on. Therefore, if the response occurred between 0 and 30 ms of the target time the researcher provided feedback by saying "You've got it!"; if the response was between 31 and 90 ms the feedback was: "You're slow/fast"; if the subject's response time was longer than 90 ms the researcher said: "You're too slow/fast".

The transfer phase took place 20 min after acquisition in order to allow the transient effects from acquisition to dissipate [23]. During the transfer phase the participants executed nine trials in the same sequence of pressing the numbers from 1 to 5 as in the acquisition phase but with the stimulus speed increased to 0.60 m/s, which changed the timing constraint to 3000 ms. The participants were informed of the change in speed but not whether it would be faster or slower than in acquisition phase. In this phase the inter-trial intervals were kept at 3 s, but no KR was provided.

Analysis of the participants' performance was based on the number of trials needed to accomplish the acquisition phase and on two error measures. The first error, Absolute Error (AE), was calculated by the absolute temporal difference between the instant the last red LED was turned on and the participant touching sensor 5 on the response box; this was used as an indicator of response accuracy. The second error measure was Variable Error[1](VE), which was based on the variability of the responses and measures performance consistency/variability.

Analyses of variance (ANOVA) were performed and the post-hoc Least Significant Difference (LSD) test was used to further explore the differences. The level of significance was set at .05 for all analyses; and statistical power will be presented when below .80. Normality and homoscedasticity assumptions for ANOVA have been checked by Kolmogorov-Smirnov and Levene's tests specifically. All data met normality criterion ($p = 0.20$), but some data did not met homoscedasticity ($p = 0.03$). Therefore, analysis using these specific data had natural log transformation applied for data correction and will be properly indicated.

Results

The results were interpreted by analyzing the number of trials required to meet the skill acquisition criterion, absolute error (AE) and variable error (VE).

Number of trials analysis

Figure 2 illustrates the results on the number of trials needed to meet the criterion level during the acquisition phase. Two-way ANOVA (age × practice schedule) showed that the young adults needed fewer trials to meet the criterion, at $F(1, 28) = 6.75$, $p = 0.015$, power = 0.70. No difference was shown for the distributed practice, at $F(1, 28) = 0.20$, $p = 0.658$, nor was a significant

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[1] For more information on these error measures (AE and VE) see Schmidt & Lee [4].
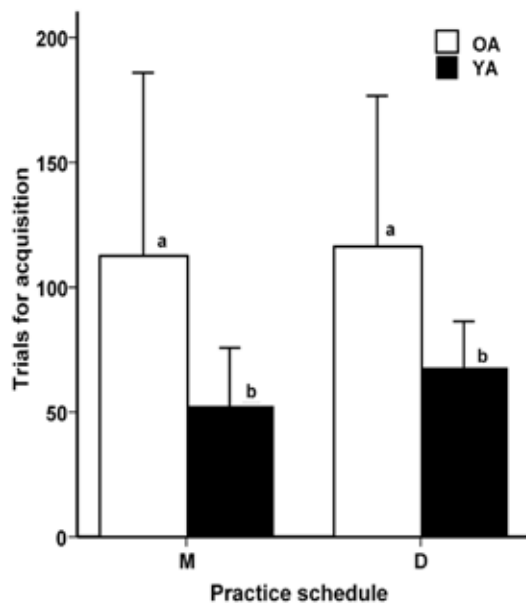
M – massed practice; D – distributed practice; OA – older adults;
YA – young adults; letters (a) and (b) indicate significant differences
at $p \leq 0.05$

Figure 2. Means and standard deviation of trials
to finish the acquisition phase

OM – older-massed; OD – older-distributed; YM – young-massed;
YD – young-distributed; # indicates within-group differences from AqL;
groups in the same solid box presented identical results ($p \leq 0.01$)

Figure 3. Mean Absolute Error (AE) and standard error
values for all groups in the first (AqF) and last (AqL)
acquisition blocks and in the second (T2) and third (T3)
transfer blocks

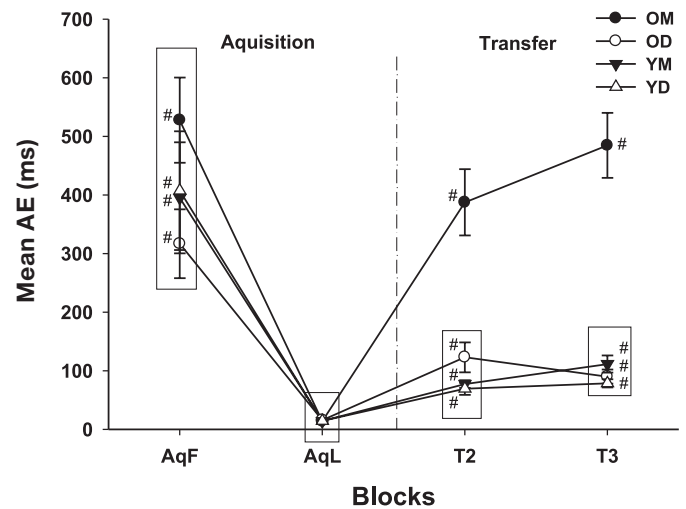interaction between the factors observed, at $F(1, 28) = 0.08$, $p = 0.779$.

Analysis of Absolute and Variable Error was performed by grouping the trials into blocks of three trials and, as participants had different amounts of practice during the acquisition phase due to the use of the criterion level presented in the methods session, only the first and last blocks of acquisition were considered for analysis. Error data were analyzed by means of two-way ANOVA (group x blocks), with repeated measures for factor 'blocks' and the interaction between both factors.

Absolute error (AE) analysis

The first comparison was between the performance in the first (AqF) and last (AqL) acquisition blocks (Fig. 3), in which ANOVA detected a main effect for blocks, at $F(1, 28) = 90.78$, $p = 0.0000$ but not for groups, at $F(3, 28) = 1.06$, $p = 0.382$, nor for interaction between the two, at $F(3, 28) = 1.10$, $p = 0.362$. The LSD post-hoc test indicated a reduction in AE from AqF to AqL for all groups ($p \leq 0.01$).

The next comparison was between acquisition and transfer through AqL and the second (T2) and third transfer blocks (T3) (Fig.3). The first three trials (T1) were relegated as they could reflect a transient warm-up decrement effect that may mask real learning effects [24, 25]. Transfer data for both AE failed to meet homoscedasticity criterion ($p \leq 0.05$). Hence natural log transformation was applied for data correction.

ANOVA showed significant main effects for groups, at $F(3, 28) = 47.38$, $p = 0.0000$ and blocks, at $F(2, 56) =$

304.24, $p = 0.0000$, and a significant group-block interaction, at $F(6, 56) = 11.11$, $p = 0.0000$. Post-hoc LSD analysis found that AE increased in all groups from AqL to T2 ($p \leq 0.001$) and from AqL to T3 ($p \leq 0.001$), and that OM differed from all the groups in T2 and T3 ($p \leq 0.001$), although there was no difference among the others; OD, YD, and YM($p > 0.05$). The amount of errors did not increase from T2 to T3 in any of the groups ($p > 0.05$). Although all groups presented an accuracy loss from acquisition to transfer, the results indicate that the performance of the OM group was the least accurate.

Variable error (VE) analysis

Analysis of the acquisition phase (AqF and AqL) showed significant main effects for blocks, at $F(1, 28) = 61.39$, $p < 0.0000$. Post-hoc LSD testing indicated that VE reduced from AqF to AqL for all groups ($p \leq 0.01$). Group comparison and group-block interaction were found to be not significant, at $F(3, 28) = 0.08$, $p = 0.46$ and $F(3, 28) = 0.91$, $p = 0.44$, respectively.

Transfer data for VE also failed to meet homoscedasticity criterion ($p = 0.008$). Hence natural log transformation was applied for data correction ($p = 0.44$).

The comparison between AqL, T2 and T3 (Fig. 4), presented significant differences between groups, at $F(3, 28) = 10.89$, $p = 0.0001$; blocks, at $F(2, 56) = 34.93$, $p = 0.0000$, and a significant group-block interaction, at $F(6, 56) = 9.46$, $p = 0.0000$. Post-hoc LSD analysis found that VE increased from AqL to T2 for all groups ($p \leq 0.05$) except for OD ($p > 0.05$), increased for all groups from AqL to T3 ($p < 0.05$) except for OD ($p > 0.35$), and that VE increased from T2 to T3 for the OM group ($p \leq 0.001$) but decreased for the OD group ($p \leq 0.001$).
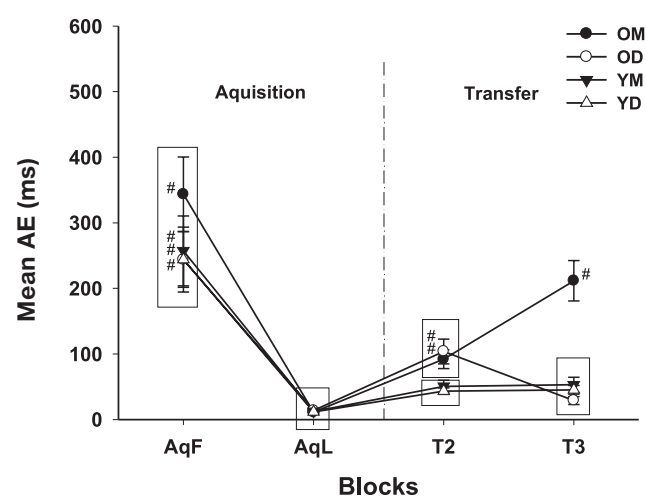
OM – older-massed; OD – older-distributed; YM – young-massed;
YD – young-distributed; # indicates within-group differences from AqL;
* indicates difference from T3 to T2; groups in the same solid box
presented identical results ($p \leq 0.01$)

Figure 4. Mean Variable Error (VE) values for all groups
in the first (AqF) and last (AqL) acquisition blocks and
in the second (T2) and third (T3) transfer blocks

Group comparisons showed that both older groups differed from the two younger ones in T2 ($p \leq 0.01$), but there was no difference between OD and OM ($p > 0.05$) or between YD and YM ($p > 0.05$). In T3, only OM differed from the others ($p \leq 0.001$). The results indicate that, despite the fact that all of the groups showed a relative increase in variability from acquisition to transfer, the older adults under massed practice presented a more representative loss of performance consistency.

Discussion

The present study investigated the effects of distribution of practice upon the motor learning of young and older adults. We proposed that the modification of a practice schedule would exert a more pronounced influence upon the learning process of older adults, which was confirmed in the experiment. The young adults did not present any behavioral divergences between massed and distributed practice, but this was not the case for older adults, as the results of the distributed group were more similar to those of the younger ones and the older adults under massed practice presented results that were poorer compared with the others.

The results from the acquisition phase showed no differences between the groups in regards to either performance accuracy (AE) or consistency (VE) as the groups started and finished this phase with similar results. The absence of differences between the groups at the end of the acquisition phase was essential for us to compare learning proficiency, as the participants were starting from a similar performance level. This also indicated that all of the groups were able to proficiently execute the proposed task.

It may be questioned that older individuals executed more trials than the younger ones during acquisition. However, this aspect does not compromise the findings of this study, as OM, even with a larger amount of practice, presented the poorest learning results. In addition, this need of additional practice is in accordance to the lower rate of performance improvement during the acquisition of new skills by older adults [26]. Nevertheless, it has to be emphasized that this augmented practice was necessary in order to ensure that all participants were tested with a similar level of experience (performance) and were able to correctly complete the task.

One interesting aspect of the data collected during the acquisition phase is that none of the groups showed a decrease in performance that is characteristic of massed practice. However, this result is not entirely surprising due in part to the different behaviors presented during the acquisition of different kind of tasks [2, 8]. Nonetheless, whether this is caused by the nature of the task or by the task itself, as already pointed by Lee & Genovese [8], is still unclear. It appears that the inter-trial intervals present in timing tasks may be enough to dissipate any fatigue-like effects that could impair performance during a massed practice schedule.

Analysis of learning among AqL, T2 and T3 showed decreased performance and increased variability for all groups, with OM presenting the poorest results. Taken together, these results and the increased number of trials required by the older groups during the acquisition phase indicate that these individuals do maintain learning capacity, although they in effect require a larger number of trials and that the amount they learn depends on the distribution of practice. When older adults are subjected to a distributed schedule, their learning performance is similar to that of a younger group, whereas under a massed schedule their learning is considerably poorer.

Although both older groups required the same amount of practice during the acquisition phase, the ones under massed practice showed a reduced and less adaptable learning behavior, as observed in the transfer test [4]. These findings are in agreement with previously stated hypotheses on distribution effects, namely those on encoding variability [27] and deficient processing [28, 29].

The deficient processing hypothesis [28, 29] proposes that the ready availability of information related to the task being learned by the information processing system may enable satisfactory acquisition but impair learning. The encoding variability hypothesis [27] suggests that increased intervals in a practice session could enable the capture and usage of more information, which would elicit the emergence of a wider view of the task and, consequently, enhance learning.

Considering these two hypotheses, we may assume that the OM group adequately performed the task during the acquisition phase due to information persistence, but this information kept in the information processing system did not require the reconstruction of an action plan. Therefore, the absence of an interval between the blocks restrained the amount of information

captured and only elicited the formation of a narrow view of the task with less competence in extracting and using relevant information and establishing the parameters of the action, which impaired transfer. On the other hand, more frequent rehearsal and retrieval plus a higher and more significant amount of information, creating a wider view of the task, may have enabled the older adults under distributed practice to learn more accurately and flexibly. However, if these hypotheses are universal in nature, why did the young adults not show similar behavior?

Neurophysiological studies have shown that aging brings about functional reductions in the sensorimotor system [12, 13] and in the brain regions connected to information processing and memory [12, 19]. Together, these data may readily support the findings of this study. With sensorimotor and SNC limitations, the elderly may benefit from longer rest intervals during practice sessions whereas young adults, due to the functional integrity of their neurological systems, may be able to learn adequately even with short intervals. In our case, the 3 s interval that was provided seems to have been enough for the younger groups to process information accordingly, thus enabling a similar learning effect between YM and YD.

Besides showing the different learning behavior of young and older adults under different practice schedules, the results have also shed some light on the learning capacity between older and younger individuals [14–17, 26]. This topic has no clear consensus, where, according to Bock & Schneider [14], the contradictions that appear in the literature may be due to the absence of controlled or standardized rest intervals during practice; the results of this study give credence to this suggestion. Apparently, sensorimotor and SNC changes may cause older adults to require longer intervals during a practice session in order to guarantee better learning, which may be as efficient as the learning shown by younger adults.

In studies comparing these two age groups, young adults are treated as the 'gold standard' of good performance, where older adults that show learning results similar to young adults are considered to have preserved their learning capacity; however, this may be the effect of modifying the practice schedule alone. Attention must be paid to the fact that, as in this study, older and young adults completed different amounts of practice and that this ought to be taken into account when comparing such results with other studies. However, it was clearly shown that the amount of intervals during a practice session may approximate or separate the amount of learning of younger and older adults. Thus, the time of the rest intervals used during practice is an important aspect that needs to be considered when comparing these two groups.

Furthermore, the results of this study strengthen other propositions in that some boundary conditions may interact with a practice schedule [5], which may

hinder or amplify its effects. This study suggests that one of the causes of the conflicting results on the distribution of practice may be related to the characteristics of the examined participants. Although studies on intra-session distribution show some schedule effects, there is no consensus on the superiority of one practice schedule over the other [1, 6, 8, 9], and some of these authors [1, 8, 9] suggest that there is no difference between massed or distributed practice on learning. However, these studies were all conducted with young individuals. In the present study, no distribution effect would have been found if only the results of the young individuals were considered. Thus, the inclusion of the older groups enabled us to determine the advantage of the distributed practice schedule. Once again, the sensorimotor functionality of younger individuals may be mentioned here, although these nonetheless are highly influenced by the kinds of tasks employed: simple laboratorial tasks. The combination of having a fully functioning information processing system and the relatively simple tasks performed in motor learning studies may account for the absence of differences between massed and distributed practice.

Despite showing results relevant in the understanding of the learning characteristics of older adults and the effects of distribution of practice, a number of issues still need to be addressed. First of all, the inter-trial interval is only one kind of practice schedule that may be used. As memory consolidation mechanisms are important for learning, more studies modifying inter-session distribution should be conducted especially considering that aging impairs memory [19, 30 for review]. In addition, there lies the need for investigating the neurophysiological mechanisms underlying the effects of distribution in order to promote a better understanding of this phenomenon.

Conclusions

A superior effect of the distributed practice schedule in comparison to massed practice on motor learning was observed in the older groups in terms of both accuracy and variability, but no difference was found between the groups of young adults. The results find that older adults are more susceptible to the effects of practice distribution than young adults: a massed schedule was found to impair older adults' learning performance, while a distributed schedule enabled them to achieve learning levels similar to those of younger individuals. Considering this similarity, the results also indicate that comparisons of motor learning between young and older adults depend on intra-session intervals and thusly need to be taken into account. Another aspect that needs to be considered is possible subject-task interaction, which may unveil the effects of distribution of practice. Further investigation is needed in order to consolidate these data and also to identify and elucidate the mechanisms related to this behavior.

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