The effect of enhanced variability after performance stabilization through constant practice

Carmen Ruano [1] , **Carla Caballero** [1] , **Francisco J Moreno** [Corresp. 1]

1 Sports Research Centre, Universidad Miguel Hernández de Elche, Elche, Alicante, Spain

Corresponding Author: Francisco J Moreno
Email address: fmoreno@umh.es

There is a controversy about the benefits of variable practice on motor learning. This study aimed to analyze the effect of variable practice after the learner stabilized his/her performance. Thirty-two healthy adults performed a computer-simulated discrete accuracy task in which they had to release a virtual ball to try to hit a target. After a pre-test, the participants were distributed into three training groups: Constant practice, Variable practice and a group that started practicing in constant conditions, and when their performance stabilized, changed to variable practice. The participants performed 44 sets of 10 repetitions of the task. A post-test and two retention tests were carried out. Variable practice did not show a significant improvement compared to constant practice. Variable practice did not show higher benefits even when performance was stabilized through constant practice, but its effects seem to be modulated by the initial variability of the learners.

1 The effect of enhanced variability after performance

2 stabilization through constant practice.

3 Carmen Ruano Masiá[1], Carla Caballero[1], Francisco Javier Moreno[1]

5 [1] Department of Sports Sciences, Miguel Hernández University, Elche, Spain.

7 Corresponding Author:

8 Francisco Javier Moreno[1]

9 Sports Research Centre. Department of Sports Sciences. Miguel Hernandez University of Elche.

10 Av. de la Universidad s/n. CP: 03202. Elche. Alicante. Spain.

11 Email address: fmoreno@umh.es

Abstract

There is a controversy about the benefits of variable practice on motor learning. This study aimed to analyze the effect of variable practice after the learner stabilized his/her performance. Thirty-two healthy adults performed a computer-simulated discrete accuracy task in which they had to release a virtual ball to try to hit a target. After a pre-test, the participants were distributed into three training groups: Constant practice, Variable practice and a group that started practicing in constant conditions, and when their performance stabilized, changed to variable practice. The participants performed 44 sets of 10 repetitions of the task. A post-test and two retention tests were carried out. Variable practice did not show a significant improvement compared to constant practice. Variable practice did not show higher benefits even when performance was stabilized through constant practice, but its effects seem to be modulated by the initial outcome variability of the learners.

Introduction

Variability is an inherent feature of motor behaviour, which can be observed in all living beings and it seems to be linked to the ability to adapt to the environment. In reinforcement learning, motor variability would allow the learners to explore the situations they are faced with, by adapting their outputs through movement variations, trying to find the best motor solution to every situation (Wu et al., 2014). This has also been explained through the Dynamic Systems Theory, under the idea that the fluctuations in motor behavior can improve the range of solutions that a person could use to fulfill the demands of a specific task (Davids et al., 2003). One of the most studied topics to facilitate motor learning has been the role of induced enhanced variability, which is known as variable practice. The formulation of variable practice was originally based on the idea of acquiring a generalized motor program in the schema theory (Schmidt, 1975). That perspective argued that variable practice facilitates the development of a more flexible schema in

38   unpredictable environments, or open skills. More recent studies, under the Dynamic System

39   Theory (DST), have argued that this kind of practice facilitates not only a better performance in

40   open environments but it also facilitates motor learning processes in closed skills (Savelsbergh et

41   al., 2010; Davids et al., 2003, 2006; Stergiou et al., 2006; Thelen, 1995).

42   Previous studies have addressed how variable practice, understood as the modifications of

43   the standard movement or task patterns of an ability had a positive effect in the learning of

44   fundamental movement skills (Caramiaux et al., 2018; Dawhale et al., 2017), and in individual and

45   collective sport skills (Menayo et al., 2012; Urbán et al., 2012; Williams & Hodges, 2005).

46   However, other studies have not found those positive results for the variable practice versus

47   constant practice, obtaining better results with this last one (Chu et al., 2013; García-Herrero et al.,

48   2016; Wulf & Schmidt, 1994). These results lay out a controversy in the application of this training

49   method.

50   An important factor that needs to be taken into consideration when interpreting the results

51   of variability training is the magnitude of the external variability load applied. According to

52   McEwen and Lasley (2002), the body's response to a physical training load has an inverted "U"

53   shape, in which very low load levels will not be enough to cause adaptations, the same as very

54   high levels could be detrimental, causing non-desired adaptations. Regarding motor learning, the

55   Challenge Point Hypothesis (Guadagnoli & Lee, 2004) suggested that learning will be reduced in

56   the presence of too little or too much information. If a task provides little information (e.g. a slight

57   difficulty for an expert performer), the learner will learn very slowly. On the other side, a very

58   difficult, or a very rich informative task for a novel performer will also diminish the learning rate.

59   From this hypothesis, the optimum amount of practice load would be a function of the skill level

60   of the individual (functional task difficulty) and the difficulty of the to-be-learned task (nominal

61 task difficulty). This idea was taken by Moreno and Ordoño (2015), who extrapolated it to variable

62 practice load. Thus, there are studies that propose a moderate variability magnitude as the optimal

63 level to obtain positive results (Caballero et al., 2017; Harbourne & Stergiou, 2009; Ranganathan

64 & Newell, 2010). In this sense, some authors have pointed out that practice individualization based

65 on the characteristics of the individual is a key issue that should be taken into consideration when

66 training variability is applied (Caballero et al., 2017). In a study carried out with handball players

67 by García-Herrero et al (2016), it was confirmed that the most experienced players reported greater

68 improvements with higher levels of practice variability, while those who were beginners needed

69 lower levels, or even the absence of extrinsic variability. That would be due to the fact that their

70 own exploratory behaviour offered enough internal variability, in line with the concept that was

71 introduced. Thus, inducing a high level of external variability in individuals with a low level of

72 dexterity could delay the search of motor solutions when facing the learning of a motor task (Wulf

73 & Schmidt, 1994). This would be in accordance with the idea of how the initial level of the learner

74 could be a factor to be taken into consideration to apply induced variability, as beginners usually

75 show larger motor variability than experienced learners (Leversen et al., 2012).

76   In this sense, Moreno and Ordoño (2015) suggested that variability implies a load the

77 organism needs to adapt to, and its effect on learning could be explained through the General

78 Adaptation Syndrome (GAS) (Selye, 1956). In the adaptation of this syndrome to motor learning,

79 it is hypothesized that when facing a practice load, an organism will experience a performance

80 decrement (alarm phase). If the magnitude of the load is below a certain tolerance threshold, the

81 organism will adapt to it (resistance phase). Nevertheless, intensities not adjusted to the individual

82 characteristics of the learner would not cause the expected effect or would even damage

83 performance. Consequently, one of the most relevant factors that needs to be considered when

84   implementing variable practice interventions could be the learning or training process stage when

85   the variability load is applied. According to Caballero et al. (2017), the effect of variable practice

86   is not the same if the individual is at an initial stage of learning or if the participant shows a certain

87   level at performing the task. Consequently, depending on these factors, the optimal variability

88   magnitude will not be the same in all learning stages.

89   Therefore, it can be said that the effect of the application of variability load in the learning

90   of a task is still unclear as it depends on many factors, such as the moment of application or the

91   magnitude of the variability load. This may be related to the fact that the variability showed by the

92   practitioner is directly connected with the effect elicited by an external variability load. From the

93   DST point of view, the application of external variability after a constant training process could

94   be a facilitator in the search for solutions, as it implies the modulation of external constraints. It

95   would also fit in with the challenge point hypothesis prediction, as the nominal difficulty of the

96   task should be adjusted to the performer's level (functional difficulty). In this sense, one of the less

97   studied factors in previous research is the moment in which the external variability load is applied

98   (Lai, Shea, Wulf & Wright, 2000). As beginners and experts seem to respond differently to variable

99   practice, the analysis of this factor could provide a possible explanation to these differences. Thus,

100   the present study has tried to analyze the effect of constant practice against variable practice,

101   applying variability at different moments of the learning process according to the level of dexterity

102   shown by the participants. The main hypothesis of this paper is that variable practice will be more

103   effective after a constant training period, once the performance is stabilized.

104

105

106   **Materials & Methods**

107

108 **Participants**

109 Thirty-five healthy, right-handed adults initially took part in the study. During the

110 experiment, three participants showed atypical results attributed to artefacts in the data collection,

111 so thirty-two participants completed the experiment (n = 32), out of which nine were females and

112 twenty-three were males (mean age 26.50±5.93 years, body height 172.33±7.58 cm, and body

113 mass 68.87±8.27 kg). None of the participants reported any kind of injuries at the moment of the

114 research or in the previous six months. Written informed consent was obtained from each

115 participant prior to testing. Data were treated anonymously, and all participants were informed of

116 the risks and benefits of the trial. The experimental procedures used in this study were in

117 accordance with the Declaration of Helsinki and were approved by the University Office for

118 Research Ethics (DPS.FMH.01.16).

119 The participants were distributed into three groups according to the kind of training they

120 were going to follow during the research: Constant, Variable and Stabilized (variability after a

121 stabilization in the performance of the task) (See Table 1 for descriptive statistics of each group).

122 The group distribution was established according to the initial performance of the participants in

123 the test to avoid its influence on the final results.

124

125 **Table 1. Descriptive statistics of the participants divided according to the kind of**

126 **training**

127

128 **Experimental procedure**

129 The task consisted of a computer simulation in which the participant used a virtual ball and

130 performed several throws trying to hit a mobile target that moved from one side of the screen to

131 the other and back. To obtain a successful throw, the ball had to intercept the mobile target within

132 a delimited area on the computer screen (the area limited by brackets in Figure 1). The task was

133 specifically designed by the researchers for this study using the Labview Software v.11 (National

134 Instruments, Texas, USA).

135   The throws were performed using a joystick connected to a dynamometer (model FSSB

136 R3 Warthog, RealSimulator, Madrid, Spain), which registered the forces applied at the antero-

137 posterior (AP) and medio-lateral (ML) axes at 100 Hz. The release angle of the ball was calculated

138 by the resultant of the combination of the forces. The joystick was placed on a table at a 30 cm

139 distance from the computer screen.

140   The participants had to perform the task with their non-dominant hand, seated on a chair

141 in front of the screen and holding the joystick. They were told to direct their forearm towards the

142 screen. The participants chose a comfortable sitting position in front of the screen, placing their

143 other hand on their thigh (Figure 2).

144

145 **Figure 1. Task scheme.** The square represents the target, which moves from one side of the screen

146 to the other. The participant had to release the ball using the joystick, so that the ball hit that target.

147 The space delimited with brackets represents the effectivity area in which the ball should hit the

148 target.

149

150 **Figure 2. Position of the participant while performing the task.**

151

152 Each participant performed a pre-test, a training period, a post-test and two retention tests (24 h

153 and one week after the first day, respectively) (Figure 3). All the tests consisted of 3 sets of 10

154   repetitions, with a 15 s rest between sets. Session 1 lasted 45 minutes, while sessions 2 and 3 lasted

155   approximately 10 minutes. In all the tests, the movement frequency of the ball was constant (0.25

156   Hz). Before starting, all the participants were instructed about the functioning of the program, and

157   they were allowed to perform 5 repetitions to get used to the program and the task. A training

158   process was performed between the pre-test and the post-test. Participants performed different

159   types of training according to the group they were assigned to. a) Constant training (Constant):

160   participants performed the same task as in the evaluation tests, in the same conditions. b)

161   Variability training (Variable): in this group, a non-structured variability practice at the objective

162   level of the task was applied (Ranganathan & Newell, 2013). The modified parameter between

163   repetitions was the movement frequency of the target, which varied in a random pattern between

164   0.125 and 0.5 Hz. According to Davids et al. (2008) and Ranganathan and Newell (2013),

165   variability practice at the objective level encourages the ability to look for the best options to

166   achieve the task goal. c) Variability after the performance stabilization during the learning of the

167   task (Stabilized): in this group, the software was set up so the participant started with constant

168   training, and the performance improvement was registered. After the seventh set of 10 repetitions,

169   the error displayed by the participant in the last two sets was compared with the error from the

170   previous sets (by calculating the difference). If any of the two last sets displayed a lower error than

171   the previous, the participant continued the constant training. Once the participant did not reduce

172   the error in two consecutive sets, the variability training started (in the same way as the Variable

173   group) and continued until the end of the training process. This was an individualized process, in

174   which each participant started variability training at the improvement plateau. Researchers decided

175   not to apply any variability load until the seventh set was reached to allow, after the pre-test, at

176   least a minimum series of 3 additional sets to assess the stabilization in the evolution of

177   performance. The number of sets performed was the same for all the groups (44 training sets of 10

178   repetitions with a 15 s rest between sets). The temporal distribution of the tests is shown in Figure

179   3.

180

181   **Figure 3. Temporal distribution of the tests.**

182

183   **Data analysis and reduction**

184   The final position of the ball was registered by the software used to record the task

185   performance (developed in LabVieW v.11). The absolute value of the distance between the ball

186   and the target (AE) was taken as the main performance indicator. The variable error (VE) was

187   measured as the standard deviation of the final position of the ball. The software computed the

188   absolute values of the distance between the ball and the center of the delimited effectivity area in

189   which the ball should impact the target (Ball-to-area), and it also computed the absolute values of

190   the distance between the target and the center of the effectivity area (Target-to-area) as

191   complementary information. An application written in MatLab R2020a (MathWork, Inc., USA)

192   was used for data analysis.

193   Participants were distributed into three groups according to the kind of training they

194   followed (Constant, Variable and Stabilized). Additionally, they were subdivided according to the

195   initial VE of the participants during the pre-test, low or high. The value of VE reflects the outcome

196   variability that the participants exhibited during the execution of the required task. As the

197   variability in the outcome is an intrinsic characteristic of the individual, this variable was selected

198   to analyse how it could be related to the effect of variable practice. Those participants who

199   displayed lower values of this variable than the mean of the sample were classified as low outcome

200 variability (LV, n = 16). Participants classified as high outcome variability (HV, n = 16) were those

201 who showed over-the-mean values of VE (Constant: n = 9, LV n = 4, HV n = 5; Variable, n = 12,

202 LV n = 5, HV n = 7; Stabilized, n = 11; LV n = 7, HV n = 4). The analysis was to explore how the

203 effect of different kinds of training would be related to the intrinsic features of each participant

204 (Caballero et al., 2017; Chrousos, 2009; García-Herrero et al., 2016).

205

206 **Statistical analysis**

207 Prior to the statistical analysis, a Kolmogorov-Smirnov test confirmed the normal

208 distribution of the data. After that, a two-way (4 x 3) mixed ANOVA was carried out. The

209 intragroup factor was the *moment of measurement* (four levels: pre-test, post-test, re-test 1 and re-

210 test 2), and the intergroup factor was the *type of training practice* (Constant, Variable, and

211 Stabilized). The interaction effect of the type of training practice on the differences between the

212 moment of the measurement was also assessed. A Bonferroni post hoc for the pair comparisons

213 was carried out for the different group divisions, the kind of training group and the initial outcome

214 variability group.

215 The subdivision according to the initial outcome variability was not included as a factor

216 due to the reduced sample size, but the effect sizes (g) were calculated applying the Hedge's

217 correction to minimize the impact of the sample size and they were categorized following Rhea's

218 standards (2004) for non-trained individuals. Additionally, a correlational analysis was also carried

219 out to test the relationship between the initial outcome variability and the improvement percentage

220 between different testing moments. The signification level and the Pearson correlation coefficient

221 were calculated.

222 The significance level for all the analysis was set at $p < 0.05$.

223

Results

225   The results of the statistical analysis are presented in the following lines. The ANOVA showed

226   significant main effects for the moment of measurement factor. All the groups showed an

227   improvement after the practice period (AE: $F_{3,87} = 26.43$, $p < 0.001$, $\eta^2 = 0.477$; VE: $F_{3,87} = 32.30$,

228   $p < 0.001$, $\eta^2 = 0.53$; Target-to-area: $F_{3,87} = 757$, $p < 0.001$, $\eta^2 = 0.21$; Ball-to-area: $F_{3,87} = 8.70$, p

229   < 0.001, $\eta^2 = 0.23$), but without significant intergroup differences.No interaction effect was

230   observed (AE: $F_{6,87} = 0.17$, $p = 0.98$, $\eta^2 = 0.01$; VE: $F_{6,87} = 0.60$, $p = 0.68$, $\eta^2 = 0.04$; Target-to-

231   area: $F_{6,87} = 0.29$, $p = 0.81$, $\eta^2 = 0.02$; Ball-to-area: $F_{6,87} = 0.28$, $p = 0.82$, $\eta^2 = 0.02$).

232

233   **Figure 4. Pairwise comparisons between tests in all the variables for the three intervention**

234   **groups (Constant, Variable and Stabilized).** AE = Absolute Error; VE = Variable Error; a =

235   significant differences compared to the pre-test, $p < 0.05$; A = significant differences compared to

236   the pre-test, $p < 0.001$.

237   The comparisons between tests in all the variables for the three intervention groups

238   (Constant, Variable and Stabilized) show statistically significant results in AE and VE (Figure 4).

239   Taking AE as the key performance indicator, the three training groups showed significantly better

240   performance in the post-test and the re-test2 compared to the pre-test, with a moderate effect size

241   (Constant group: g = 1.56 and g = 1.27, respectively; Variable group: g = 1.43 and g = 1.33,

242   respectively; Stabilized group: g = 1.63 and g = 1.12, respectively).

243

244   **Figure 5. Evolution of the absolute error (AE) and dispersion (SD) of the participants of the**

245   **three training groups: Constant, Variable and Stabilized.**

246

247   The evolution of the error and its dispersion among the three training groups is presented

248   in Figure 5. In the constant group, a progressive decrease can be seen (with typical transient

249   increases and decreases), especially at the beginning of the mean error values during the training

250   series. The error values of the post-test are lower than those of the pre-test. Despite the slightly

251   higher values in the first retention test, these did not reach the pre-test values. In the second

252   retention test, the error values were similar to those of the post-test. The behaviour of the standard

253   deviation is very similar to the error values in this group.

254   The variable group did not show a clear trend in performance during the training series. An

255   unstable pattern of error and, more clearly, of its dispersion can be observed. It can be seen how

256   the error remained constant, with some peaks and valleys, during all the training process, the same

257   as the dispersion, which showed a marked variable behaviour during the whole practice period.

258   Nevertheless, the post-test results, with lower error values than in the training series and the pre-

259   test, would elucidate latent improvement in performance. This is corroborated by the values of the

260   mean error in the retention tests. The variability in the error, expressed by the dispersion values,

261   followed a similar behaviour with lower differences.

262   The stabilized group, showed a marked decrease both in mean error vales and in its

263   dispersion at the beginning of the training. Then (coinciding with the application of variable

264   practice), the error increases and, at one point, it starts decreasing again progressively. This

265   increase in the mean error values is not seen in the SD, which maintains a more constant trend,

266   although it fluctuates slightly more at the end of the practice period. The behaviour in the post-test

267   and retention tests was similar to the variable group.

268   A correlational analysis was carried out to test the possible relationship between the initial

269   variability in the outcome and the improvement in performance (error reduction) due to the

270   training. This improvement was computed by calculating the difference between the initial error

271   in the pre-test and the three tests measured after the training (post-test, re-test 1, and re-test 2).

272   Higher values in improvement mean greater decrements in AE. Statistically significant

273   correlations were found between the initial VE and the improvement in AE after the training phase

274   (difference between the pre-test and the post-test), $r(30) = 0.474$, $p = 0.006$. Initial VE also

275   correlated with the improvement shown in the re-test 2, $r(30) = 0.468$; $p = 0.007$. The correlation

276   between the initial outcome variability and the improvement shown in the re-test 1 was not

277   significant.

278   Regarding the comparisons made within the subjects of each group according to their initial

279   VE, we can see some remarkable size effects (g) according to Rhea's criterion (2004). In the

280   constant training group, the LV participants showed a moderate effect size ($g = 1.21$) between the

281   pre and the post-test. That difference was higher in the HV participants, showing a large effect size

282   ($g = 2.29$). The effect size of the differences between the pre and the re-test 1 and 2 were low for

283   the LV participants ($g = 0.92$, $g = 0.94$) and moderate for the HV participants ($g = 1.87$, $g = 1.80$).

284   In the variable training group, it can be seen that, conversely, the effect size was larger in the LV

285   participants than in the HV participants in the pre-test vs the post-test (LV: $g = 2.75$, HV: $g = 1.17$)

286   and in the pre-test vs the re-test1 (LV: $g = 2.04$, HV: $g = 0.96$). These effects changed in the

287   comparison the pre-test vs the re-test2 (LV: $g = 2.86$, HV: $g = 4.27$). In the stabilized training

288   group, there were less differences between the LV and the HV participants in the effect of the

289   training (LV: pre-test vs post-test: $g = 4.70$; pre-test vs re-test1: $g = 2.21$; pre-test vs re-test2: $g =$

290   2.79; HV: $g = 2.29$; $g = 0.96$; $g = 4.27$).

291

Discussion

293   The main goal of this study was to assess if variable practice is beneficial for learning and

294   if the controversial results observed in the previous literature can be explained by the incidence of

295   other variables, such as the moment when variable practice is applied or the individual

296   characteristics of the learner.

297   As it was expected, within the measured variables, the variable that was more clearly

298   affected by training was the absolute error, which was the main performance variable. All groups

299   improved their performance after practice, without there being clear differences between the

300   different training strategies. Moreover, we can observe that the different training strategies led to

301   different responses in the improvement of the participants. Although all the participants improved,

302   the larger effect sizes shown by the participants in the variability training group suggest that the

303   addition of variability in practice implies a beneficial training load (Moreno & Ordoño, 2015;

304   Savelsbergh et al., 2010). However, the lack of clear differences between groups and the absence

305   of interaction effects hinders the obtention of clear conclusions about the benefits of variable

306   practice and it reinforces the need to discuss what factors could mediate in the relationship between

307   variable practice and performance.

308   The introduction of variable practice once the participants stabilized their performance was

309   manipulated as one possible factor that could affect the differential effects of variable training.

310   This is based on the idea that the amount of variability applied in a session needs to be matched to

311   the skill level of the performer, in line with the Challenge Point Framework (Guadagnoli & Lee,

312   2004). Dhawale et al. (2019) suggested that, at the beginner level, low-task variability could be

313   initially beneficial to guide exploration towards finding a functional solution. As the level of the

314 learning increases, higher variability would be present in the individual, in the task and in the

315 environmental constraints to promote a more dexterous behaviour. Previous studies pointed out

316 that individualization is a fundamental issue, and the characteristics of the individuals should be

317 considered when variability is applied (Caballero et al., 2017). In this experiment, it was expected

318 that a previous period of stabilization by practicing under constant practice would prepare the

319 learners to exploit the benefits of variable practice better. Once the initial functional solution was

320 acquired, variability would encourage exploration of new successful and adaptive solutions to the

321 task. Nevertheless, the absence of between-groups differences has encouraged the need for a more

322 in-depth exploration of how the differences between learners inside the groups would mediate the

323 effect of variable practice. Barbado et al. (2017) proposed that the learners with higher initial

324 variability would exhibit a greater exploratory behaviour that allows them to learn in a greater

325 way. This higher initial variability would reduce the need for the enhanced variability proposed by

326 the practitioner. This can be related to the challenge point hypothesis that proposes that, when the

327 difficulty of a task increases, the available knowledge about the task has to increase in parallel to

328 enhance the learning process, especially when the level of the practitioner is low, being less

329 necessary when the level increases (Guadagnoli & Lee, 2004).

330 It can be seen how constant practice did not result in great variations of performance during

331 the training process, opposed to variable practice, which caused an irregular behaviour in the

332 performance during all the performance series. Moreover, in the stabilized group, the trend towards

333 the increase of the error after stabilization would indicate the effect of external variability

334 application. In this group, a performance increase can be seen at the end of the training period,

335 indicating an adaptation after the *alarm state* caused by the variability application (Moreno &

336 Ordoño, 2015; Selye, 1956). Moreover, the performance values in all the tests were similar in all

337 kinds of training, which can indicate that, in general terms, all the different ways of training

338 enhanced performance.

339 Focusing on the correlational analysis, the individuals who showed a greater outcome

340 variability (i.e. greater VE) in the pre-test displayed greater improvements than those who were

341 initially more consistent. This is consistent with the fact that those participants with poorer initial

342 performance had more room for improvement. Thus, it could be possible to interpret that the

343 individual's performance level should be taken into consideration to decide what kind of training

344 strategy will be more suitable for his progression (Caballero et al., 2017; García-Herrero et al.,

345 2016). Supporting this idea, the effect size results could indicate that participants with higher

346 outcome variability could benefit more from less external variability, and the opposite would

347 happen with more consistent participants, while the moment of application could play a key role

348 here (Lai et al., 2000). This lays the basis for future investigations with a higher number of

349 participants which can be divided according to their initial performance and variability.

350 In the constant training group, the participants with higher initial error variability increased

351 their performance with clearer changes. These participants also showed poorer initial performance

352 and, therefore, more room for improvement was expected. However, it has to be noted that their

353 error values at the post-test and re-tests were similar to those obtained by the learners with lower

354 variability in their initial outcome, suggesting that these last participants did not exploit the benefits

355 of this kind of practice. In the group that trained with variable practice from the beginning, the

356 participants with lower initial error variability reduced their error to a greater extent in the post-

357 test and in the first retention test than the participants with high initial error variability. In this

358 sense, Caballero et al. (2017) proposed that the training load should be adapted to the individual's

359 level. Barbado et al. (2017) and Garcia-Herrero et al (2016), also postulated that the learners that

360   showed a more variable performance could have an exploratory behaviour which allows them to

361   learn in a greater way. However, in both cases (high and low initial error variability participants)

362   there was a progressive improvement during the training process. More information is needed

363   about the effect of additional variable practice when learners exhibit low levels of variability.

364   All the participants exhibited a decrement in their performance during the application of

365   variable practice. However, the removal of variable practice resulted in a considerable

366   improvement of the performance. This could be explained by the adaptation to the training load,

367   as proposed by Moreno and Ordoño (2015). The applied variability caused a transitional loss of

368   performance in participants, who improved when they practiced without enhanced variability and

369   after a resting period. Previous studies suggested that poising the system above a "critical point"

370   of the edge of chaos (Bowes & Jones, 2006), in which the amount of variability would lead to

371   excessive instabilities, would limit the search for new solutions (Dhawale et al. 2019).

372   Finally, the fact of applying variability after stabilizing the performance of the participants

373   with constant practice did not show a differential improvement in the final result compared to

374   variability training from the start of the process. Applying constant training to facilitate

375   stabilization was not reflected in an improvement of performance. This could be especially useful

376   for those participants with high initial error variability. Again, the application of variable practice

377   resulted in a reduction in performance. When variable practice was removed, in the post-test, the

378   performance increased, and this improved performance continued in the retention tests, but with

379   similar levels to those obtained during the stabilization series.

380   The implications of the results in this experiment should be taken with caution due to the

381   sample limitations of the study. It is important to consider that this task was completely new for

382   the participants, and the sample showed heterogeneous results. Although the results indicated

383   different training impacts in each participant depending on their inner features, the reduced sample

384   size in each subgroup hinders statistical between-group differences. The enlargement of the sample

385   in further research is encouraged to be able to perform a more in-depth analysis and to obtain

386   clearer conclusions.

387   In addition, other interesting variables could be registered to try to obtain additional

388   information about the participant´s exploration, such as the decision time since the stimulus

389   appeared until the participant responded, as this factor could have some influence on the precision

390   of the task. In this study, only the variability in the outcomes has been studied. Recent studies have

391   outlined that the role of task-relevant variability could be implied in faster learning (Haar, van

392   Assel & Faisal 2020). Thus, this lays a new field of research for future studies. Additionally, it

393   must be pointed out that the tests were all applied in constant conditions, and a transference test

394   was not included. Previous studies have supported the good results of variable practice in

395   transference tests compared to constant training (Pacheco & Newell, 2018). Although it was not

396   the aim of the study, this type of tests could have provided additional findings according to the

397   strategy of practice, so it could be taken into consideration in future research.

398
399
400   **Conclusions**

401   After the analysis of the results, it can be concluded that the practice of the task has

402   improved performance in all cases. Variable practice has not caused a significantly greater

403   improvement when compared to constant practice. Applying variable practice after a stabilization

404   period training with constant practice has not induced a significant improvement either. Regarding

405   the decrease in performance after the variable practice load as an adaptation phenomenon (Moreno

406   & Ordoño, 2015), this decrease could only be appreciated when the stabilization period, using

407 constant practice, was applied. Nevertheless, the effect of variable practice seems to be modulated

408 by the initial outcome variability of the participants. Those participants with higher initial

409 variability values showed higher improvement trends than those with lower values when constant

410 practice was applied. However, participants with a smaller variability in their outcome did not

411 show this positive effect of the constant practice in their performance.

412 The stabilization of the performance period after constant practice applied to high initial

413 variability learners has not shown a positive effect that prepares them to face a variable practice

414 load. It is still unknown if longer constant practice periods would be effective to prepare the

415 individuals with high variability to benefit from variable practice effects. Further studies are

416 needed to study more in-depth on how to adjust the practice conditions to the participant's

417 characteristics.

418
419
420

421 **References**

422 Barbado, D., Caballero, C., Moreside, J., Vera-García, F. J., & Moreno, F. J. (2017). Can the

423 structure of motor variability predict learning rate? *Journal of Experimental Psychology:*

424 *Human Perception and Performance,* 43(3), 596.

425 Caballero, C., Luis, V., & Sabido, R. (2012). Efecto de diferentes estrategias de aprendizaje sobre

426 el rendimiento y la cinemática en el lanzamiento del armado clásico en

427 balonmano. *Motricidad. European Journal of Human Movement,* 28, 83-100.

428 Caballero, C., Moreno, F. J., Reina, R., Roldán, A., Coves, A., & Barbado, D. (2017). The role of

429 motor variability in motor control and learning depends on the nature of the task and the

430 individual's capabilities. *European Journal of Human Movement,* 38, 12-26.

431   Caramiaux, B., Bevilacqua, F., Wanderley, M. M., & Palmer, C. (2018). Dissociable effects of

432   practice variability on learning motor and timing skills. *PloS one*, 13(3), e0193580.

433   Chrousos, G. P. (2009). Stress and disorders of the stress system. *Nature reviews*

434   *endocrinology,* 5(7), 374.

435   Chu, V. W. T., Sternad, D., & Sanger, T. D. (2013). Healthy and dystonic children compensate for

436   changes in motor variability. *Journal of neurophysiology,* 109(8), 2169-2178.

437   Davids, K., Bennett, S., & Newell, K. M. (2006). *Movement system variability*. Champaign,

438   Illinois. Human Kinetics.

439   Davids, K., Button, C., & Bennett, S. (2008). *Dynamics of skill acquisition: A constraints-led*

440   *approach*. Champaign, Illinois. Human Kinetics.

441   Davids, K., Glazier, P., Araujo, D., & Bartlett, R. (2003). Movement systems as dynamical

442   systems. *Sports medicine*, 33(4), 245-260.

443   Dhawale, A. K., Miyamoto, Y. R., Smith, M. A., & Ölveczky, B. P. (2019). Adaptive regulation

444   of motor variability. *Current Biology*, 29(21), 3551-3562.

445   Dhawale, A. K., Smith, M. A., & Ölveczky, B. P. (2017). The role of variability in motor learning.

446   *Annual review of neuroscience*, 40, 479-498.

447   Garcia-Herrero, J. A., Sabido, R., Barbado, D., Martinez, I., & Moreno, F. J. (2016). The load of

448   practice variability must be regulated in relation with learner expertise. *International*

449   *Journal of Sport Psychology*, 47(6), 559-570.

450   Guadagnoli, M. A., & Lee, T. D. (2004). Challenge point: a framework for conceptualizing the

451   effects of various practice conditions in motor learning. *Journal of motor behavior*, 36(2),

452   212-224.

453   Haar, S., van Assel, C. M., & Faisal, A. A. (2020). Motor learning in real-world pool

454   billiards. *Scientific reports*, *10*(1), 20046. https://doi.org/10.1038/s41598-020-76805-9

455   Harbourne, R. T., & Stergiou, N. (2009). Movement variability and the use of nonlinear tools:

456   principles to guide physical therapist practice. *Physical therapy*, 89(3), 267-282.

457   Lai, Q., Shea, C. H., Wulf, G., & Wright, D. L. (2000). Optimizing generalized motor program

458   and parameter learning. *Research quarterly for exercise and sport*, 71(1), 10-24.

459   Lee, T. D., Magill, R. A., & Weeks, D. J. (1985). Influence of practice schedule on testing schema

460   theory predictions in adults. *Journal of Motor Behaviour*, 17(3), 283-299.

461   Leversen J.S.R., Haga M., Sigmundsson H. (2012) From Children to Adults: Motor Performance

462   across the Life-Span. *PLoS ONE* 7(6): e38830.

463   https://doi.org/10.1371/journal.pone.0038830

464   McEwen, B. S., & Lasley, E. N. (2002). The end of stress as we know it. *Joseph Henry* Press.

465   Menayo, R., Moreno, F.J., Fuentes, J.P., Reina, R. & Damas, J.S. (2012). Relationship between

466   motor variability, accuracy, and ball speed in the tennis serve. *Journal of Human Kinetics*,

467   33, 45-53. https://dx.doi.org/10.2478%2Fv10078-012-0043-3

468   Moreno, F.J. & Ordoño, E.M. (2015). Variability and practice load in motor Learning. *RICYDE.*

469   *Revista Internacional de Ciencias del Deporte*, 39, 62-78.

470 Pacheco, M. M., & Newell, K. M. (2018). Learning a specific, individual and generalizable

471   coordination function: evaluating the variability of practice hypothesis in motor learning.

472   *Experimental brain research*, 236(12), 3307-3318.

473 Ranganathan, R., & Newell, K. M. (2010). Motor learning through induced variability at the task

474   goal and execution redundancy levels. *Journal of Motor Behaviour*, 42(5), 307-316.

475 Ranganathan, R., & Newell, K. M. (2013). Changing up the routine: intervention-induced

476   variability in motor learning. *Exercise and sport sciences reviews,* 41(1), 64-70.

477 Rhea, M. R. (2004). Determining the magnitude of treatment effects in strength training research

478   through the use of the effect size. *Journal of strength and conditioning research*, 18, 918-

479   920.

480 Savelsbergh, G. J., Kamper, W. J., Rabius, J., De Koning, J. J., & Schöllhorn, W. (2010). A new

481   method to learn to start in speed skating: A differencial learning approach. *International*

482   *journal of sport psychology*, 41(4), 415.

483 Schmidt, R. A. (1975). A schema theory of discrete motor skill learning. *Psychological review*,

484   82(4), 225.

485 Selye, H. (1956). *The stress of life*. New York: McGraw-Hill Book Co.

486 Stergiou, N., Harbourne, R. T., & Cavanaugh, J. T. (2006). Optimal movement variability: a new

487   theoretical perspective for neurologic physical therapy. *Journal of Neurologic Physical*

488   *Therapy*, 30(3), 120-129.

489 Sterling, P., & Eyer, J. (1988). Allostasis: A new Paradigm to Explain Arousal Pathology. In S.

490   Fisher & J. Reason (Ed.), *Handbook of Life Stress, Cognition and Health.* (pp. 629-649)

491   New York: John Wiley & Sons.

492   Thelen E (1995). Motor development. A new synthesis. *American Psychology* 50 (79 –95).

493   doi:10.1037/0003-066X.50.2.79

494   Urbán, T., Hernández-Davó, H., & Moreno, F. J. (2012). Variabilidad cinemática en relación con

495   el rendimiento en el saque en jóvenes tenistas. Motricidad. *European Journal of Human*

496   *Movement*, 29, 49-60.

497   Williams, A. M., & Hodges, N. J. (2005). Practice, instruction and skill acquisition in soccer:

498   Challenging tradition. *Journal of sports sciences*, 23(6), 637-650.

499   Wu, H. G., Miyamoto, Y. R., Castro, L. N. G., Ölveczky, B. P., & Smith, M. A. (2014). Temporal

500   structure of motor variability is dynamically regulated and predicts motor learning

501   ability. *Nature neuroscience,* 17(2), 312-321.

502   Wulf, G., Lee, T. D., & Schmidt, R. A. (1994). Reducing knowledge of results about relative versus

503   absolute timing: Differential effects on learning. *Journal of motor behaviour*, 26(4), 362-

504   369.

505

506
507

Figure 1

Task scheme.

The square represents the target, which moves from one side to another at a movement frequency of 0.25 Hz in each repetition. The participant had to throw the ball using the joystick, so that it impacts that target. The space delimited with brackets represents the effectivity area in which the ball should impact the target.

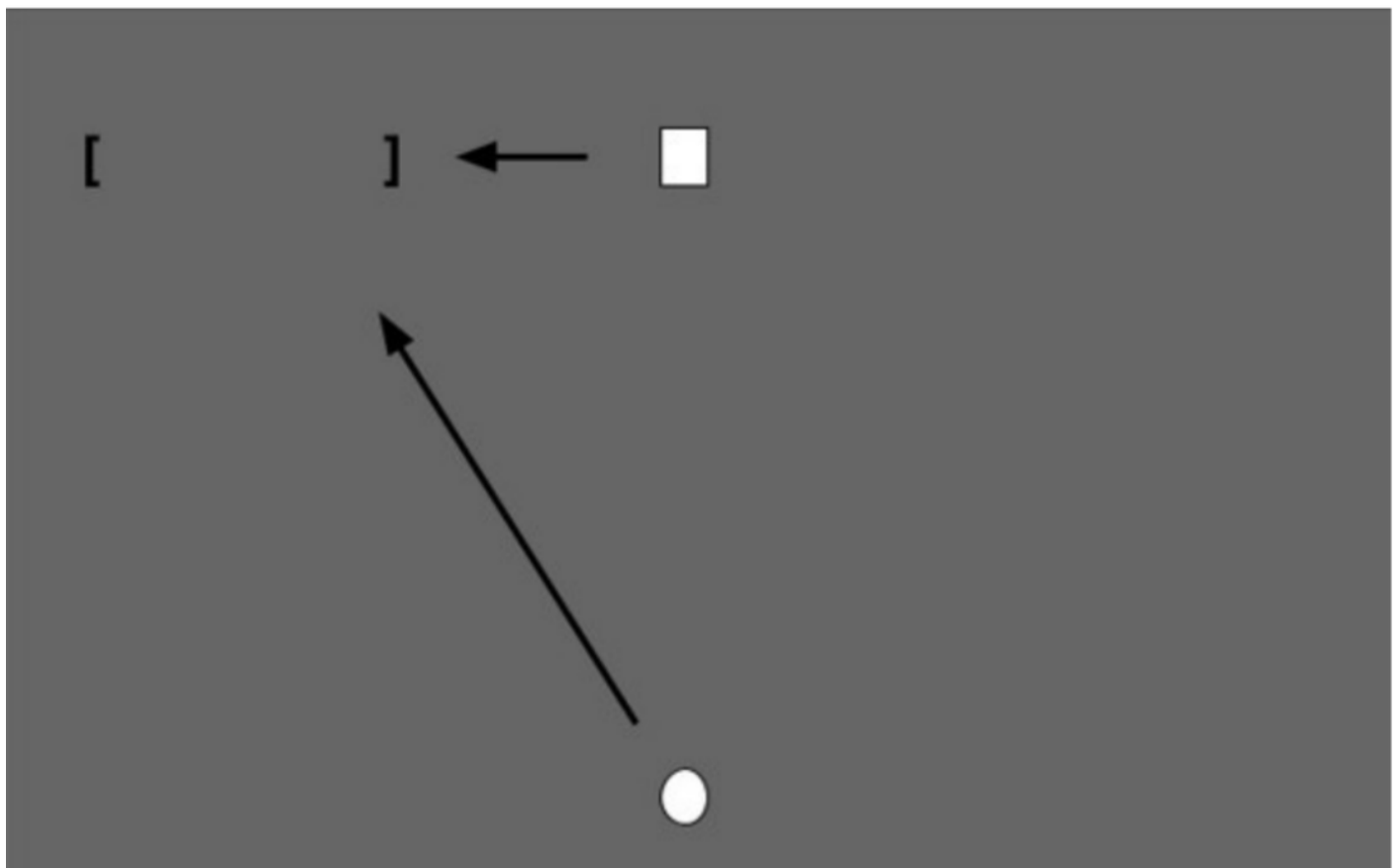



Figure 2

Position of the participant while performing the task.

Figure 3

Temporal distribution of the tests.

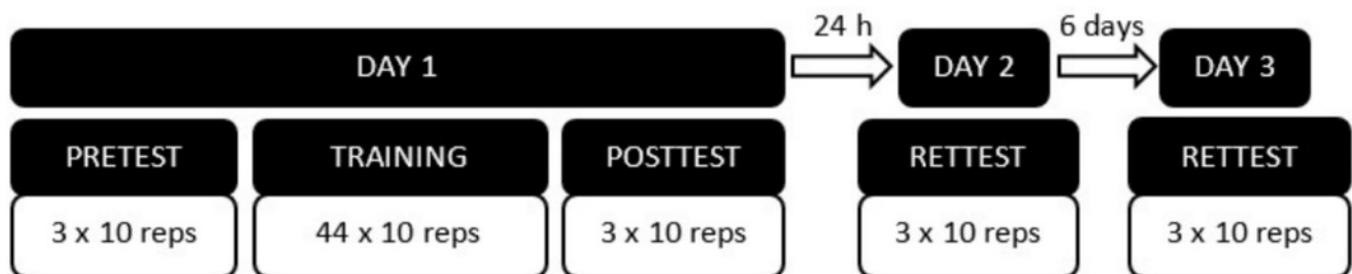



Figure 4

Pairwise comparisons between tests in all the variables for the three intervention groups (Constant, Variable and Stabilized).

a = significant differences compared to the pre-test, p<0.05; A=significant differences compared to the pre-test, p<0.001.

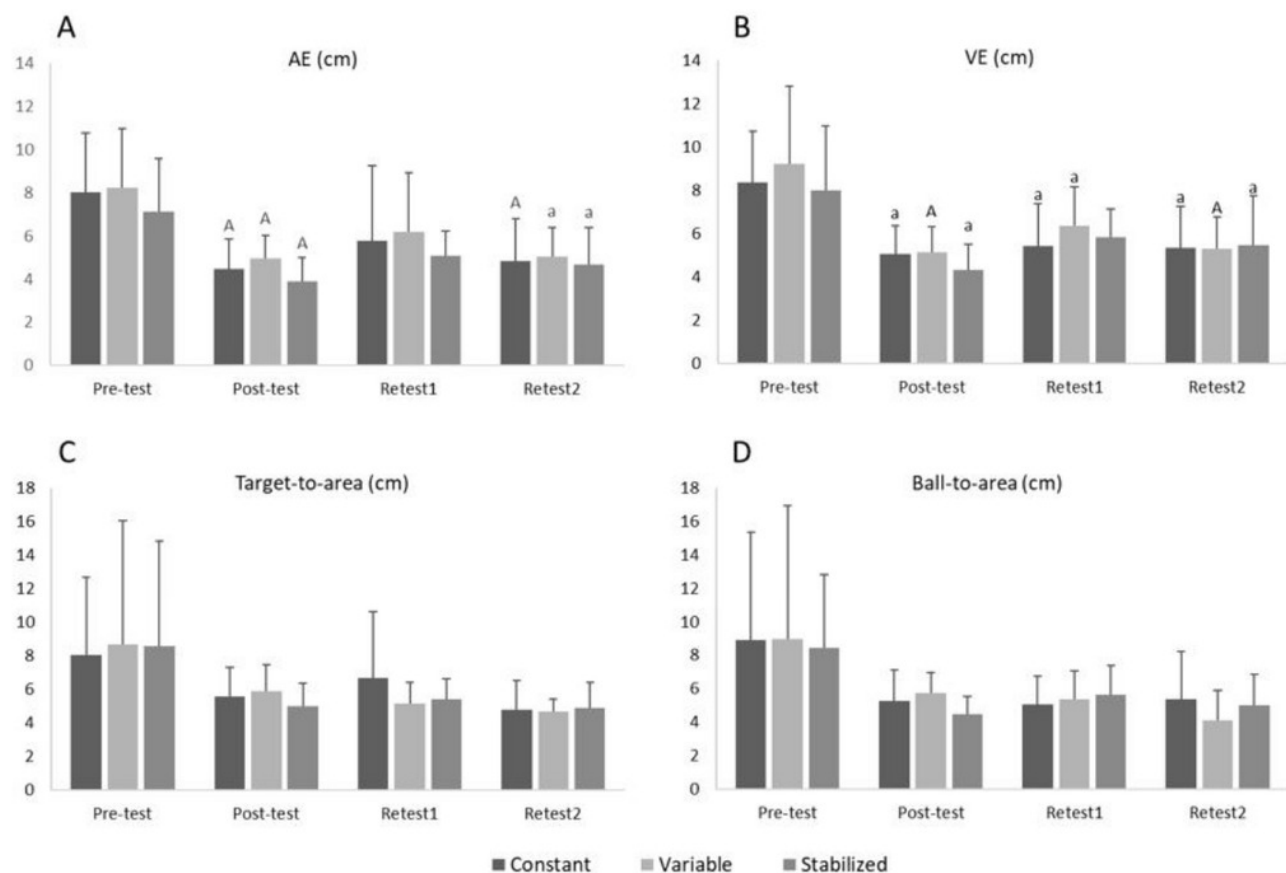
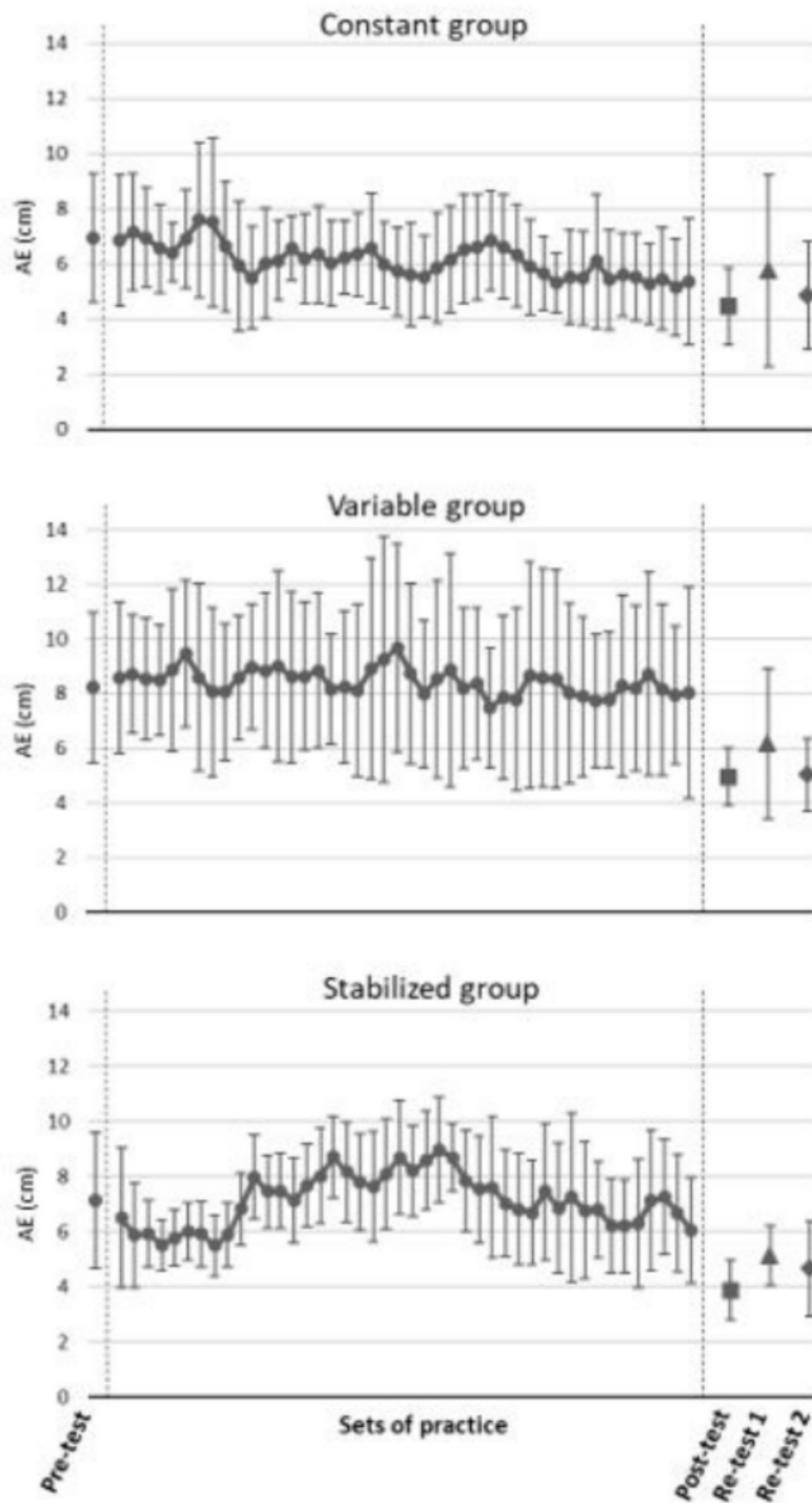



Figure 5

Evolution of the absolute error (AE) and dispersion (SD) of the participants of the three training groups: Constant, Variable and Stabilized. Note: Mean = AE

Descriptive statistics of the participants divided according to the kind of training

1   **Table 1. Descriptive statistics of the participants divided according to the kind of**

2   **training**

Group	Age (years)	Height (cm)	Body mass (kg)
Constant (n=9)	27.25±5.17	172±4.92	67.63±7.56
Variable(n=12)	25.82±3.71	168.91±9.47	67.91±11.09
Stabilized (n=11)	26.63±8.27	176±5.66	70.73±5.42