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1 **Influence of motor imagery modality on first serve performance in tennis players**

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3 Running head : Motor imagery, preference, modality and service performance

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27 **Influence of motor imagery modality on first serve performance in tennis players**

28

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Abstract

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Key words: service, mental imagery, imagery ability, tennis, preference.

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53 **Influence of motor imagery modality on first serve performance in tennis players**

54 Motor Imagery (MI) can be defined as the deliberate cognitive simulation of movements
55 (Seiler et al., 2022), which shares the control mechanisms and neural substrates with actual
56 movement (Hanakawa, 2016). MI is a mental technique that is very frequently used by coaches and
57 athletes to improve motor performance (Ladda et al., 2021; Simonsmeier et al., 2020), particularly
58 in racket sports (Cécé et al., 2020) and tennis (Robin & Dominique, 2022). Some studies have
59 shown beneficial effects of MI used alone, compared to control (e.g., rest or reading) conditions
60 (e.g., Gentili et al., 2010; Ram et al., 2007). However, these effects are generally less compared to
61 those obtained following actual practice (Toth et al., 2020).

62 Indeed, it is important to note that a large number of research studies have shown greater
63 positive effects when MI was combined with the actual execution of actions (Guillot et al., 2013;
64 Robin & Dominique, 2022; Schuster et al., 2011). For example, in a study of serve returns, it was
65 found that MI sessions combined with real executions improved the accuracy of shots in expert
66 tennis players (Robin et al., 2007). Beneficial effects were also observed on service performance
67 when MI preceded physical execution (e.g., Desliens et al., 2011; Dominique et al., 2021; Guillot et
68 al., 2012). This is why we hypothesize that the simulation of a motor action, before its real
69 execution, should make it possible to improve performance.

70 According to Frank et al. (2014), during MI participants solicit the mental representation of
71 the simulated action (e.g., a serve in tennis). The mental representation are constructed from
72 sensory modalities coming from the environment (e.g., visual images) or of the body (i.e.,
73 kinesthetic images) as recently indicated by Dominique et al. (2021). Indeed, there are different
74 types of MI, including internal and external visual imageries and kinesthetic imagery. These three
75 types of MI are the main modalities used by athletes, and in particular tennis players (Robin &
76 Dominique, 2022).

77 Internal visual imagery (IVI) involves imagining, in the first person, seeing the performance
78 of a motor action as if looking through one's own eyes (Robin et al., 2020). During external visual

79 imagery (EVI), athletes must mentally simulate movement as a spectator, also known as third
80 person MI, as if filmed by a camera (Hall, 2001). Finally, the kinesthetic imagery (KI) modality
81 consists of imagining what one feels when performing a mentally simulated action and focuses on
82 the sensations of force, speed, stretching, relaxation or effort involved in the movement (Robin et
83 al., 2020).

84 A wide range of researches revealed that MI and execution involved activation of very
85 similar cerebral structures at all stages of motor control (Crammond, 1997). However, several
86 studies have also observed specific brain activity patterns for each of the IVI, EVI and KI
87 modalities (e.g., Jiang et al., 2015; Seiler et al., 2015; 2022). For example, Guillot et al. (2009)
88 showed that KI mainly activated motor-associated structures and the inferior parietal lobule
89 whereas visual MI activated predominantly the visual-related areas and superior parietal lobule. In a
90 sporting context, many authors have emphasized that MI modalities are very important factors to
91 consider (Cumming & Ste-Marie, 2001; Robin & Dominique, 2022) when one wishes to use MI
92 practices with athletes. Indeed, each imagery modality can have differentiated impacts on motor
93 performance (Hardy & Callow, 1999). For example, White and Hardy (1995) observed differential
94 effects of visual imagery modalities, for a motor task in which environmental changes induced
95 planning constraints. Indeed, the authors examined the use of IVI and EVI in the acquisition of a
96 motor skill based on processing of environmental signals (e.g., slalom task). The results showed
97 that the participants who used IVI made fewer spatial errors during a transfer test (i.e., new route)
98 than those who used EVI.

99 On the contrary, the EVI has shown positive effects with tasks consisting in accurately
100 reproducing body shapes such as karate katas (Hardy & Callow, 1999). In the latter study, 25 expert
101 karatekas learned a new kata using IVI or EVI. The results revealed that EVI was significantly more
102 effective than IVI. Similar results were obtained, in novice athletes who had to learn a gymnastic
103 sequence (Hardy & Callow, 1999). Finally, KI seems to be beneficial for inter-segmental
104 coordination actions (Hardy & Callow, 1999) or muscle strength (Yao et al., 2013). According to

105 Ridderinkhof and Brass (2015), KI which is based on the internal activation of anticipatory images
106 of the effects of the action, is linked to predictive motor control. The authors mentioned that this
107 mechanism makes it possible to improve motor performance on the basis of internal emulation of
108 the action.

109 With regard to tennis, the results of the literature concerning the effects of MI on the
110 performance of motor skills such as the serve are more heterogeneous. Indeed, studies have shown
111 that the combination of real practice and EVI, focusing on the trajectory of the ball and the target
112 area to be hit, improved the speed and accuracy of serves in tennis players (e.g., Dominique et al.,
113 2021; Dominique & Robin, 2020; Guillot et al., 2013; Robin et al., 2020). However, other authors
114 have observed superior service performance following KI practice (e.g., Dana & Gozalzadeh, 2017;
115 Féry & Morizot, 2000).

116 This difference in results could in particular find an explanation at the level of the
117 experience of the participants. Indeed, Hardy and Callow (1999) showed that a certain degree of
118 expertise in the task was necessary to use the KI in particular. However, Di Corrado et al. (2019)
119 showed that expert tennis players were able to achieve vivid, sharp and controllable internal,
120 external and kinesthetic visual images. In addition, the authors evoked that the players were able to
121 use all three different MI modalities. Another explanation could come from the preference of
122 athletes for a particular imaging modality: KI, IVI or EVI as mentioned by Callow and Roberts
123 (2012). Thus, in athletes who are used to doing MI in a sporting context, in particular on a tennis
124 court before performing motor actions such as the service, it is possible that there is a differentiated
125 effect on performance depending on the MI modality imposed by coaches or chosen by athletes.
126 Additionally, the latter may have developed a preference for a given kinesthetic or internal visual
127 or external visual imagery perspective (Callow et al., 2013; Guillot et al., 2013). According to
128 Callow and Roberts (2012) few studies, and to our knowledge none in the field of tennis, have
129 focused on the differentiated effects of imagery preferences and MI modalities on motor
130 performance, despite of their possible interactive effects (Callow et al., 2012). We could consider

131 that the MI tennis player's preference could potentially influence their performance on a mentally
132 simulated task such as serving.

133 The aim of this pilot study was to evaluate, in expert tennis players, if the modalities as well
134 as the preference of MI had an influence on their service performances, when they used motor
135 imagery, preferential or imposed by the instructions, before serving. While, consistent with
136 previous research, players should benefit from imagery practice, the main hypothesis of this study
137 was that performance improvement could be positively influenced by their MI preference.

138 **Method**

139 **Participants**

140 Twenty males (Mage = 18.6 years; \pm 4.7 years) tennis players (rankings of the French
141 Tennis Federation between 15/1 and 2/6, which corresponds to 4.5 and 5.5 US/Canada ranks), with
142 between 9 and 13 years of regular practice, voluntarily participated in this study (see Table 1 for
143 general characteristics). The current study was carried out on Reunion Island (France). The players
144 had to compete at regional and national level competitions, and to train regularly at least 3 times a
145 week. The players did not present any particular disorder or history relating to their vision or motor
146 skills. All participants, or their legal representatives when they were minors, signed a consent form.
147 The experimental protocol was approved by the local University Ethics Committee (ACTES Urp5-
148 4-017-23) and the study was performed in accordance with the Declaration of Helsinki (2013).

149 Insert Table 1

150 **Materials and Procedure**

151 Prior the start of the experimental phases, MI ability was assessed to ensure that the sample
152 did not include participants with difficulty doing motor imagery. All the tennis players fulfilled the
153 movement imagery questionnaire 3rd French and validated version (MIQ-3f: Robin et al., 2020).
154 This questionnaire is composed of 12 items that assess individual KI, EVI and IVI modalities. Each
155 MIQ-3f item corresponds to a single movement of the leg, arm or whole body that was physically
156 performed before being mentally simulated in the specified MI modality. The tennis players then

157 rated the difficulty or ease they had in forming the mental representation of the movement using
158 two 7-point Likert-type scales (ranging from 1 = very difficult to feel/see to 7 = very easy to
159 feel/see) referring respectively to KI, IVI and EVI modalities. The psychometric properties of the
160 MIQ-3f (internal consistency: reliability score ≥ 0.88 for the three subscales) and test-retest
161 reliability (intraclass correlation coefficients: 0.87 for internal visual imagery, 0.86 for external
162 visual imagery, and 0.88 for kinesthetic imagery) proved to be satisfactory (Robin et al., 2020).
163 Additionally, the players were asked to indicate which MI ability they preferred.

164 Then, the current study that was carried out on an outdoor tennis court “greenset” type,
165 included 4 experimental sessions with repeated measures (counterbalanced) and spread over 4
166 weeks, one session per week.

167 During each experimental session, the players began with a standardized 30-minute warm-
168 up (i.e., jogging, sprint, controlled pop up rally, and 12 warm-up services), see Robin et al. (2022)
169 for a similar procedure. Then, the participants performed 20 first service balls, alternating between
170 the right and left sides, then continued the exchange with a receiver who had a similar level of play
171 and classification, like in a game situation. For each service, the speed (measured with a radar gun:
172 SR3600 Sports Radar type placed on the ground) and the percentage of success of the first balls
173 (measured with an Ipad Pro equipped with SWING VISION software placed on the ground) were
174 noted by the experimenters. All sessions were also filmed with two Canon HD cameras, Legria HF
175 G25. Finally, an efficiency score was estimated, blindly, by three experts (i.e., federal lines judges
176 and qualified tennis coach certified by the French Tennis Federation) who observed returns of
177 serves and were instructed to give a score ranging from 0 to 5 evaluating the difficulty in which the
178 receivers found themselves following the serves (see Dominique et al., 2021 for a similar
179 procedure). In order to determine the inter-rater reliability regarding the scores, Cohen’s Kappa were
180 calculated and showed strong levels of agreement (Kappa > 0.89).

181 During the control session, the participants were instructed to only physically perform the
182 services, without using MI or other mental strategy. At the end of this session, the experimenter
183 asked them if they had used a mental technique before serving.

184 During the internal visual imagery session, before each first ball, the players had to imagine
185 themselves, as if they were seeing themselves with their own eyes (or if they had a "Go Pro" on
186 their head), performing a service.

187 During the external visual imagery session, the participants were instructed, before
188 physically serving, to imagine seeing themselves in the third person performing a service as if they
189 were filmed with a camera placed on the side.

190 During the kinesthetic imagery session, they had to imagine feeling the sensations (of
191 strength, relaxation, speed for examples) generated and evolving during a service, before actually
192 realizing it.

193 At the end of each of the sessions including MI, the players had to evaluate the vividness of
194 the mental images produced with the imagery quality index comprising a Likert scale ranging from
195 1 ("Unclear and faint mental representation") to 6 ("Perfectly clear and vivid mental
196 representation") (for a similar procedure, see Robin et al., 2021).

197 **Data Analysis**

198 The vivacity scores of the mental images produced during MI served as a control variable
199 (see Robin et al., 2019 for a similar procedure). For each point achieved during the experimental
200 sessions, the performance of the serve was reflected by the average speed of the ball measured with
201 the radar, by the percentage of success of the first ball, and by the efficiency score. The dependent
202 variables were normally distributed (Kolmogorov-Smirnov test) and had homogeneous variances
203 (Levene test). For each of these dependent variables, the experimental condition (Control vs. IVI vs.
204 EVI vs. KI) repeated measures ANOVAs were calculated. In addition, normalised difference
205 scores, corresponding to the difference between the speed, success or efficiency score values in
206 control session and the values in each MI (IVI or EVI or KI) session divided by the values in

207 control session and multiples by one hundred, were also calculated and submitted to repeated
208 measures ANOVAs with the condition (C—IVI vs. C—EVI vs. C—KI). Alpha was set at 0.05 for
209 all analyses, effect sizes (η_p^2) were indicated and post-hoc analyzes were performed using Newman-
210 Keuls tests.

211 **Results**

212 **Imagery ability**

213 None of the tennis players reported having difficulty performing MI and participants
214 reported having vivid and clear images before serving (Mean = 5.2; SD = 1.4), and could be
215 considered as “good imagers” (Robin & Blandin, 2021) according to their MIQ-3f scores ($M_{IVI} =$
216 5.3 , $M_{EVI} = 5.0$, $M_{KI} = 4.9$). In addition, all of them declared that they frequently resorted to MI
217 during training and matches.

218 **Percentage of Success**

219 The ANOVA computed on the percentage of successful serve revealed a significant main
220 effect of the condition $F(1, 3) = 4.781$, $p < .01$, $\eta_p^2 = 0.21$. As illustrated in Figure 1, the post-hoc
221 test revealed that the participant had higher percentage of success of the service in the IVI (M = 55
222 %) and KI (M = 59 %) conditions (a trend .08 was observed for EVI condition, M = 52%) than in
223 the control condition (M = 45%).

224 Insert Figure 1

225 **Service Speed**

226 The statistical analysis for the service speed revealed an absence of significant main effect
227 of the condition $F(1, 3) = 2.5$, $p > .05$, $\eta_p^2 = 0.09$ (please see Table 1).

228 Insert Table 2

229 **Efficiency Scores**

230 The ANOVA computed on the efficiency scores revealed a significant main effect of the
231 condition $F(1, 3) = 10.12$, $p < .01$, $\eta_p^2 = 0.35$. As illustrated in Figure 2, the post-hoc test revealed
232 that the participant had higher efficiency scores in the IVI (M = 1.8) and KI (M = 2.0) conditions

233 than in the control ($M = 1.5$) and EVI ($M = 1.5$) conditions. Finally, the players had higher scores in
234 the KI than in the IVI conditions.

235 Insert Figure 2

236 **Imagery Preference**

237 Nine, eight and three participants indicated that their preferred MI modality was IVI, KI and
238 IVE respectively. In addition, it seems important to note that by looking specifically at the results
239 obtained by the players in each of the experimental conditions (i.e., Control, IVI, IVE and KI),
240 according to their imaging preference, we noticed that 14 (i.e., 70%) and 13 (i.e., 65%) of them
241 achieved a higher percentage of success and efficiency scores respectively, in their preferred MI
242 modality.

243 **Percentage of Success Normalised Difference Scores**

244 The ANOVA revealed an absence of main effect of condition $F(1, 2) = 1.55, p > .05, \eta_p^2 =$
245 0.07 . There was no significant difference between the normalised difference score in IVI
246 ($M=31.5\%$), KI ($M=41.1\%$) and EVI ($M=16.2\%$) conditions.

247 **Service Speed Normalised Difference Scores**

248 The ANOVA revealed an absence of main effect of condition $F(1, 2) = 0.43, p > .05, \eta_p^2 =$
249 0.02 . There was no significant difference between the service speed normalised difference score in
250 IVI ($M=-2.9\%$), KI ($M=-4.6\%$) and EVI ($M=-4.8\%$) conditions.

251 **Efficiency Normalised Difference Scores**

252 The ANOVA revealed a significant main effect of condition $F(1, 2) = 15.21, p < .01, \eta_p^2 =$
253 0.45 . As illustrated in Figure 3, the post-hoc tests revealed that the participant normalised difference
254 score, compared to control condition, was higher when using the IVI ($M=28.1\%$) and KI
255 ($M=42.3\%$) than EVI ($M=7.6\%$) modalities. Finally, the players had higher normalised different
256 scores in the KI than in the IVI conditions..

257 Insert Figure 3

258 **Discussion**

259 The aim of this study was to evaluate the effects of motor imagery modalities and
260 preferences on first serve performance in skilled tennis players.

261 As hypothesised, the results of the current study revealed that the participants benefited from
262 MI when they used this mental technique before serving in match condition. Indeed, in the IVI and
263 KI conditions (a trend for IVE) the tennis players had significant higher percentage of success of
264 service compared to the control condition (i.e., in which the participants only performed physical
265 execution). In addition, the results regarding the normalised difference score, which is calculated
266 based on difference with the control condition, revealed increases in percentage of success in the
267 service of more than 41%, 31% and 16% when using KI, IVI and IVE respectively. These results
268 are consistent with those of previous research work that have shown the beneficial effect of MI in
269 sport performances (e.g., Guillot & Collet, 2008; Ladda et al., 2021; Mizuguchi et al., 2012), racket
270 sports (Cécé et al., 2020), tennis (Atienza et al., 1998; Cherappurath et al., 2020; Dominique et al.,
271 2021; Fekih et al., 2020; Robin et al., 2023) and more particularly in closed motor skills such as
272 service (Coelho et al., 2007). As evoked by Hanakawa (2016) MI shares the control mechanisms
273 and neural substrates with actual movement. Indeed, premotor cortex that is activated during MI
274 (Guillot et al., 2009) involves the planning and preparation of actual movements (Cisek & Kalaska,
275 2004). Therefore, internal simulation of action, during MI, can facilitates improved motor
276 performance (Ridderinkhof & Brass, 2015).

277 However, and as previously evoked by Callow and Roberts (2012), each MI modality can
278 have differentiated effects on motor performance. Indeed, the results of the current study also
279 revealed greater efficiency scores and efficiency normalised difference score in the KI condition
280 compared to the other MI (i.e., IVI and EVI) conditions. This result confirms the results obtained by
281 Féry and Morizot (2000) who observed higher service performance when using KI than EVI
282 modality. Hardy and Callow (1999) evoked that the use of KI can be particularly beneficial when
283 participants have certain degree of expertise at a task, because it is easier to imagine sensations of
284 strength, relaxation or contraction of controlled movement (Fourkas et al., 2008). The effect of KI

285 could be due to the fact that this MI modality increases the corticospinal excitability (Stinear et al.,
286 2006) and activates the preparatory planning stages that lead to motor action (Jeannerod, 2006). In
287 addition, KI activates more motor-associated structures than visual imagery, which predominantly
288 activates the occipital regions (Guillot et al., 2009), which could promote motor control and
289 performance in a closed motor skill such as serving.

290 As for the KI condition, the results also revealed that participants had higher percentage of
291 success of the service, as well as efficiency normalised difference score, in the IVI condition
292 compared to the EVI condition. Previous studies showed beneficial effect, on motor performance
293 and precision, when using IVI (e.g., Mizuguchi et al., 2015; Robin et al., 2007) or KI (e.g., Desliens
294 et al., 2011; Fekih et al., 2020) modalities during MI intervention in skilled tennis players. The IVE
295 modality has shown beneficial effects in improving serve performance in non-expert young tennis
296 players (e.g., Mamassis, 2005) likely due to the fact that this modality may be useful for
297 memorizing standardized movements (Hardy & Callow, 1999). Once a technical motor action (e.g.,
298 the service in tennis) is automated, it is possible that athletes prefer using “internal” imagery
299 perspectives, which includes a variety of inputs from different sensory modalities (Mizuguchi et al.,
300 2012) to mentally generate movement by oneself, compared to “external imagery” which consists in
301 visualizing the motor action as a spectator (Yu et al., 2016). The latter authors mentioned that EVI
302 requires athletes to engage in more complex processing than IVI, due to allocentric operations that
303 must be integrated into the egocentric coordinates of the imagers, therefore requiring a additional
304 mental processes. Finally, Barr and Hall (1992) found that athletes tended to use IVI rather than
305 EVI as a preparation strategy.

306 In the current study, the higher performance obtained when using KI and IVI compared to
307 EVI, could also be explained by the MI preference of the participants (most of them, who
308 frequently used mental simulation, preferred using KI and IVI modalities). Robin and Dominique
309 (2022) recently evoked that MI training should be based upon individual characteristics such as MI
310 preferences and the results obtained in the current study seems to be consistent with this suggestion.

311 Indeed, almost a third of the participants achieved a higher percentage success and efficiency scores
312 of first services balls in their preferred MI modality. This very important point needs to be
313 confirmed, and future research including differentiating the players based on their MI preference, in
314 independent groups performing a similar procedure, should be done before generalization.

315 A first limit to this study could come from the MIQ-3f questionnaire, which is based on
316 simple movements that could be considered to be a little distant from the motor gestures made by
317 tennis players in matches or during training. As, to our knowledge, there are no MI ability tools
318 specifically developed for tennis, it would be interesting to create a questionnaire integrating
319 movements such as the forehand, the backhand, the smash, the volley or the serve in order to be
320 based on mental representation of actions more specific to tennis. It is also important to note that
321 the sample of 20 participants can be considered relatively small, and limits the power of this
322 exploratory study, particularly regarding MI preference given that we end up with 9, 8 and 3 players
323 preferring the IVI, KI and EVI modalities, respectively. The results of this study need to be
324 confirmed with a larger sample of players allowing for larger groups of MI preferences. Finally, the
325 current study focused on the performance of the first serve but due to its natural stress and anxiety
326 (Robin et al., 2022), it might be interesting to investigate the influence of MI modality on the
327 performance of the second serve too.

328 **Conclusion**

329 Consistent with previous studies showing that tennis players who performed MI before
330 serving had higher performances than in a control condition (i.e., physical execution), the main
331 results of this pilot study revealed that the participants achieved higher percentage of success and
332 efficiency scores in their preferred MI modality. These results lead us, in an applied way, to suggest
333 to skilled tennis players to determine their MI preference and to have recourse to the mental
334 simulation of a successful serve before serving the first balls in match condition. In an applied
335 manner, it will also be recommended that coaches use motor imagery, integrated into training, and

336 determine the players' IM preferences in order to benefit from the positive effects of this mental
337 technique.

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342 The Authors declare that there is no conflict of interest.

343 **Data Availability Statement**

344 All the data used in this study are available and will be sent on request.

345

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516 **Figure captions**

517 **Figure 1.** *Percentage of service success measures in the Control, Internal Visual Imagery (IVI),*
518 *External Visual Imagery (EVI) and Kinesthetic Imagery (KI) conditions (** $p < .01$)*

519

520 **Figure 2.** *Efficiency scores of service in the Control, Internal Visual Imagery (IVI), External Visual*
521 *Imagery (EVI) and Kinesthetic Imagery (KI) conditions (** $p < .01$)*

522

523 **Figure 3.** *Efficiency Normalised Difference Score in the Control—Internal Visual Imagery (C—*
524 *IVI), Control—External Visual Imagery (C—EVI) and Control—Kinesthetic Imagery (C—KI)*
525 *conditions (* $p < .05$; ** $p < .01$)*

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547 **Table 1**548 *General characteristics of the players*

Measurements	Minimum	Maximum	Mean	Standard deviation
Age (years)	17	22	18.6	4.7
Training (years)	9	13	11.2	1.9
Body weight (kg)	72	93	79.4	5.6
Body height (cm)	174	197	181.1	9.4

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576 **Table 2**

577 *Mean service speed measured during the Control, Internal Visual Imagery (IVI), External Visual*
 578 *Imagery (EVI) and Kinesthetic Imagery (KI) conditions*

	Control	IVI	EVI	KI
Mean (Km/h)	147.7	144.3	141.6	142.1
Standard deviation	12.8	12.1	13.9	8.9

579 Note: IVI (Internal Visual Imagery), IVE (External Visual Imagery), KI (Kinesthetic Imagery), $p >$
 580 $.05$ (no significant difference between sessions).

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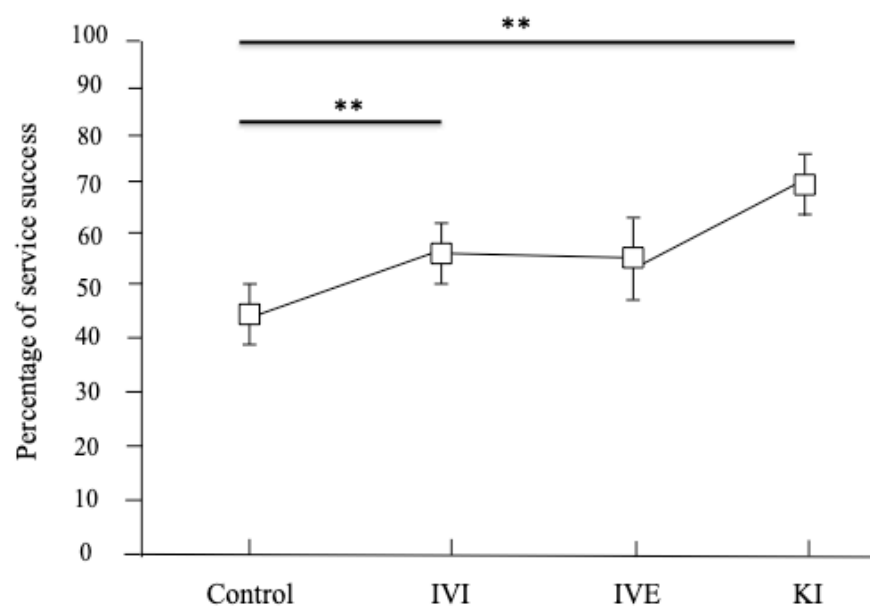
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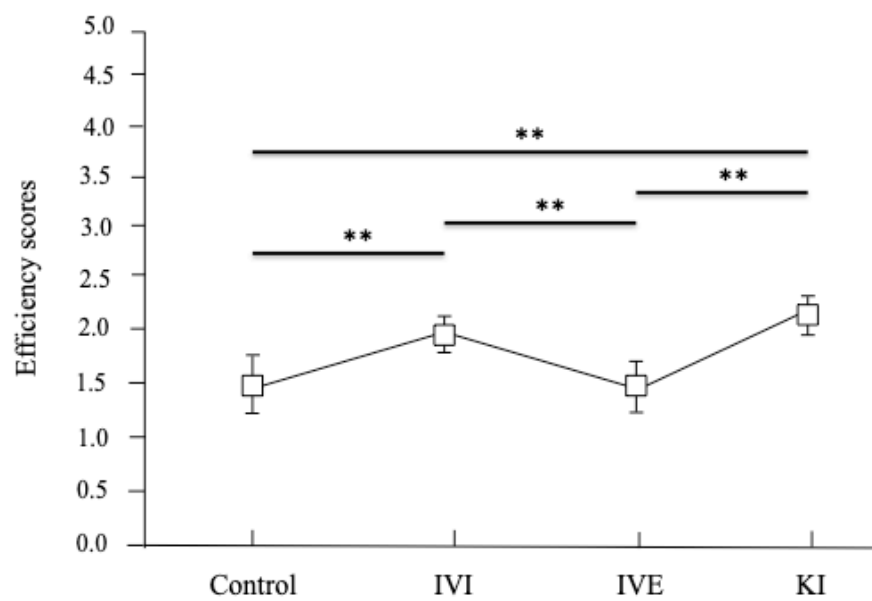
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