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The effect of contextual interference on the learning of adapted sailing for people with spinal cord injury

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Abstract

The aim of this study was to determine the effect of contextual interference on learning of adapted sailing for people with spinal cord injury. Seven participants with traumatic spinal injury were selected to undergo learning in an adapted boat equipped with wind-measuring instrument. A learning program, defined by two conditions, (1) blocked practice and (2) random practice, was applied. In blocked schedule, fixed sequence of two maneuvers consist of tacking on a close-hauled course (45°–55°) and gybing on a broad reaching course (135°–145°). In random schedule, the same maneuvers were carried out randomly. Eight 30-min practice sessions were carried out over a period of 2 weeks, in 3 days per week. Velocity Made Good was analyzed in the familiarization test, pre-test, post-test, and retention test. The learning program was effective in both random and blocked practice conditions on all participants. However, there is an evident variability in the results. This study demonstrates the suitability of applying contextual interference to facilitate the learning of adapted sailing. The variability of the results could be related to the heterogeneity of the participants and suggests the need for further research that can provide information about how restricted mobility affects the learning process.

Keywords

Sailing, learning, navigation, spinal cord injury, variability

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1. Introduction

In the history of learning to sail, there have been several attempts to standardize learning (i.e. Royal Yachting Association, 2020; Sail Canada, 2020; U.S. Sailing, 2020). However, all of them lack the necessary scientific knowledge to validate the practice programs. The problem lies in the fact that, to date, no research has systematized the processes and methodologies for learning to sail using scientific criteria. Similarly, the effects of learning this sport on people with spinal cord injuries (SCIs), who have movement restriction characteristics and a variety of musculoskeletal dysfunctions that can condition the techniques used for handling the boat, are unknown.

Such standardization is impossible to achieve in this type of population, where the affectations and mobility restrictions, specific to the type and level of the injury, are combined with the unstable factors of a learning environment such as the sea and weather conditions. This circumstance should largely determine the basic research in motor learning in people with SCIs. Therefore, we propose to rule out designs that involve comparing groups against others more appropriate for the early stages of research, which take into account the individual and his or her progress, such as case studies. These studies have been commonly used in clinical practice, to establish the scientific knowledge base and propose hypotheses for more rigorous studies (Kazdin, 2008). To solve the traditional problems of data analysis by visual inspection characteristic of this type of design and the subjectivity inherent in these

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techniques, Campbell and Herzinger (2010) recommended the application of complementary statistical analysis. In this regard, some authors suggest the use of indices to estimate the magnitude of the effect size, based on non-overlapping data (Parker et al., 2011), and a procedure to assess the significance of changes in single-case designs (Jacobson & Truax, 1991; Sanz & García-Vera, 2015). With these considerations, we propose the analysis of the effects of learning to sail on people with SCIs using these techniques.

In the sport of sailing, the objective of the teaching methodology is to get the sailor to react to different stimuli in handling the boat and adapting to the weather conditions. Under this assumption, the variable practice of the sport technique is viewed as a factor that is able to generate destabilization of the execution, leading the practitioners to a sudden discovery of individual movement patterns from the exploration of his or her perceptual-motor landscape (Davids et al., 2008). This would allow the adaptation to the task's constraints, and to the characteristics of the learner, increasing motor efficacy. The variability in practice is linked to those principles proposed from the complex dynamic systems theory (Glazier et al., 2003). The training process could be explained from the need to generate destabilization in the attractors (Schöner & Kelso, 1988a, 1988b) or stable patterns of the system's behavior. These perturbations aim to reach a new state from the self-organization of the system's components—degrees of freedom (DOF)—in the presence of noise (Frank et al., 2008), thus contributing to the spontaneous generation of motor patterns conferring maximum efficacy to movements.

To ensure that the benefits provided by adapted sailing are achieved, we must ensure that a correct method is used during the initial phases of motor learning (Duarte & Culver, 2014). One of the variables to consider in defining the best approach to learning programs is the need to carry out continuous bodily adjustments in the handling of the boat during navigation, due to the instability of the environment and the large number of DOF involved in the actions needed in the management of the vessel. The need for continuous bodily adjustments leads us to dynamical approach of the learning process using methodologies that are oriented toward contextual interference (CI) or variability of practice, which presents a dynamic character and does not lend themselves to standardization (Rojhani et al., 2017). This approach has the advantage of being able to increase the sailors' ability to adapt to the environment.

The CI effect predicts that a random order of practice for multiple skills is superior in facilitating learning compared to a blocked order. While practicing tasks with high CI (using random, interleaved practice), it is usually difficult to learn during the acquisition phase (Farrow & Buszard, 2017; Jo et al., 2020). However, positive results are obtained in the retention and transfer phases, relative to learners who practiced with reduced CI (using blocked, repetitive practice; Shea & Morgan, 1979).

Past results based on the forgetting-reconstruction hypothesis (Lee & Magill, 1983, 1985) and the elaboration hypothesis (Shea et al., 1985; Shea & Zimny, 1983) have been acquired using cognitive models mostly tested in laboratory situations. The studies evaluating these approaches propose that a high CI would enhance the learning ratios by increasing the mental effort elicited during the execution of the tasks, allowing for different points of information to be maintained in the sensory memory (Li & Vaczi, 1999) or work of learners, and by facilitating the reconstruction of action plans (Shea & Zimny, 1988). Contextual uncertainty, according to Prado et al. (2017), is indicated in motor situations characterized by high variability, as in the case of sailing. This forces the sailor to continuously adjust his or her motor solutions depending on the environment. The effects of CI in an uncertain environment are justified by the two concepts mentioned above: forgetting-reconstruction hypothesis (Lee & Magill, 1983, 1985) and elaboration hypothesis (Shea et al., 1985; Shea & Zimny, 1983). Practice of motor skills in sports such as sailing requires great mental motor skills. This forces the sailor to continually compare and contrast his or her repertoire of motor tasks (elaboration hypothesis). In addition, the handling of the boat is a task characterized by its variability, which forces the sailor to forget pre-established motor skills and rebuild new ones, a situation very similar to that described in the random practice and supported by forgetting-reconstruction.

In addition to these cognitive models, which also provide scientific support, for the purposes of this study, we took into consideration perspectives applicable to field work and unstable environments, such as those involved in sailing. Based on the review conducted by Latash (2010), the effects of high CI can also be explained from the ecological perspective (Schöllhorn, 2016). Such a view would incorporate an understanding of the navigator, the boat, and the environment (sea conditions) as a complex dynamic system of mutually interacting elements, influenced by a high (non-redundant) DOF. Learning how to handle the boat in an unstable sea environment could be conceived as a progressive approximation of the actual configuration of the motor system to a referent configuration by means of a neuronal mechanism that leads to a state of equilibrium and stabilization against perturbations present in the practice environment.

This process of discovery and control of multiple DOF by neuronal mechanisms is necessary to effectively address such disturbances and is managed by the central nervous system (CNS). These mechanisms do not progress toward a single optimal solution, but rather a wider range of solutions (Pesce et al., 2019) that can facilitate adaptation to the environment. In this sense, studies in the field of neurophysiology have shown that neurons of the dorsal premotor and the supplementary motor areas are recruited early and extensively in conditions of high CI, improving the neural connections between the two regions. This high neuronal activation may be fundamental for the optimization of adaptive processes (i.e. control of the DOF) both at the start of learning and in the long term (Cross et al., 2007; Lin et al., 2011; Wright et al., 2016). In support of this conceptual framework, Lin et al. (2018) have shown that motor practice through CI starts with the early phase of memory consolidation, likely by driving offline functional connectivity with respect to the premotor cortex immediately after practice. This finding suggested that neuronal connectivity could be improved by maintenance of acceptable levels of difficulty during motor practice.

When applying CI during the learning of adapted sailing, the need for continuous interaction of the learner with a changing and unstable environment may necessitate the transit through states of instability and stability, a problem which could be solved by having increasing control over the DOF. This progression would make the learner's actions more flexible and increase his or her motor performance. Learning facilitation, therefore, may be derived from an optimization of neuronal connections between different areas of the CNS that are implicated in learning.

Due to the variability in motor maneuvers used in controlling the boat, learning programs based on the manipulation of CI are a logical option for learning adapted sailing. CI provides a framework for organizing the sequence of skills to be acquired with respect to the order in which the tasks are presented. Random (e.g. BBABAA ...) and blocked (e.g. AAA ... BBB ...) schedules are the procedures most frequently used to change the amount of CI generated in a practice environment. Under this organization of the motor tasks, the learner never repeats the same order in the execution. Random schedule creates relatively high interference throughout training due to the rapid changes in task demands across trials. On the contrary, during blocked schedule, the learner always repeats the same order in the execution of the motor tasks. This schedule creates less interference since it entails executing the same motor task repeatedly prior to the introduction of an alternative (Wright et al., 2016). Recent studies point to an improvement in the retention and transfer phases by applying CI with randomized practice (Farrow & Buszard, 2017; Jo et al., 2020; Prado et al., 2017). However, these results should be interpreted with caution, while avoiding any generalization, because the works of Prado et al. (2017) and Graser et al. (2019) suggested the existence of potential bias in the results of most of the research in this field, considering the high levels of heterogeneity in the participants involved, motor tasks used, and environmental contexts (i.e. inside vs outside the laboratory). These same authors point to the need to expand the body of knowledge relating CI variables and motor learning programs in special populations such as those with SCIs (Graser et al., 2019).

Many SCIs show impairments in dynamic balance control (Day et al., 2012), which is one of the main motor functions for handling the boat during sailing. Some relevant research on motor learning in this group of people suggests that the disturbances, such as compensatory movements, applied during motor learning in people with SCIs cause, among other adaptations, adjustments of the skeletal system (Shadmehr & Mussa-Ivaldi, 1994) to better facilitate the control of movements. In this respect, Roemmich and Bastian (2015) also suggested that the disturbances may involve different neural response patterns, resulting in better retention of learning when applied slightly or more gradually, but worse retention when the disturbance is greater or more abrupt (Smith et al., 2006). According to Wu et al. (2014), motor variability is an essential feature of motor learning that is actively regulated for more efficient motor learning. Yet it is unclear how the variability of practice impacts the motor learning of controlling boat in people with SCI.

Considering the proposed effects of CI, insufficient studies have been dedicated to investigating the use of real-world game-based training to assess acquisition and learning of sports skills in relation to the CI effect (Cheong et al., 2016). From a therapeutic point of view, practicing non-laboratory tasks might improve the translation to other daily life relevant tasks (Graser et al., 2019). More and more authors propose the use of CI as a rehabilitation tool in populations with motor problems, specifically in populations with SCIs. If CI can be used as a rehabilitation tool, it can be added to the benefits obtained during navigation for this type of special populations, such as continuous postural adjustment and mainsail sheet and rudder grip (Jo et al., 2020). Investigations such as those carried out by Graser et al. (2019) in non-laboratory designs found improvements in retention and subsequent transfer, which can help populations with SCIs incorporate engine patterns acquired in offshore navigation into their daily routines. The above studies may provide clear indications that practicing the motor skills characteristic of the sport of sailing, under CI conditions, could increase the control of DOF, facilitating the learning of boat handling when SCI restricts the movement of learners.

Therefore, we propose to apply CI to facilitate the learning of the tack and the gybe, two fundamental maneuvers used in handling the boat in adapted sailing. The tack consists of changing the direction of the boat moving upwind, crossing the wind direction with the bow. The gybe involves changing the sail side as the

Table 1. Physical-functional disabilities of the participants.

Participants	Level of injury
1	Thoracic vertebra 1 (incomplete)
2	Thoracic vertebra 10 (complete)
3	Lumbar vertebra 4 (incomplete)
4	Thoracic vertebra 12 (incomplete)
5	Lumbar vertebrae 4 and 5 (incomplete)
6	Thoracic vertebra 2 (complete)
7	Lumbar vertebra 1 (complete)

wind passes through the stern from one side of the ship to the other. In both cases, the navigator needs to exhibit adequate motor control to govern the boat and address the disturbances and instabilities that emerge during navigation in open waters.

Therefore, the aim of this research was to determine the effect of CI on the learning of adapted sailing for people with SCI. Our hypothesis is that random practice and conditions of high CI associated with greater variability in form of practice will produce higher rates of learning compared to blocked practice and conditions of reduced CI related to a more repetitive practice.

2. Materials and methods

2.1. Population sample

Seven male participants were recruited using a non-probabilistic sampling selection method by convenience (Arnal et al., 1992), with mean age of 37.6 ± 5.3 years. The participants in the study were chosen from ASPAYM (Association of Paraplegics and Great Physical Disabilities of Murcia, Spain) and users of the "TetraSport" gymnasium, located in Valencia (Spain). The inclusion criteria were as follows: (1) older than 18 years of age, (2) a rating of "apt" on a disability certificate that specifies the type of injury, (3) a level of autonomy determined by the presence of a complete and/or incomplete SCI between thoracic vertebra 1 and lumbar vertebra 5, (4) use of a wheelchair, and (5) no past experience in sailing as a sport. According to these criteria, of the 14 participants selected randomly, only 7 eventually completed the entire learning program. All were distributed to blocked ($N = 4$) or random ($N = 3$) practice. The physical-functional disabilities affecting the participants are shown in Table 1. All participants provided written informed consent to participate in the research. The research protocol was approved by the Ethics Committee of the Catholic University of Murcia (Spain).

2.2. Apparatus and measures

For the practice of sailing, an adapted Hansa 303 model vessel (Barcelona, Spain) was used (Figure 1). This boat

Figure 1. Adapted boat model "Hansa 303" used in the learning program.

Figure 2. Wind equipment, consisting of a display panel and a wind vane, installed on the mast of the boat.

model was also used in other studies (e.g. Rojhani et al., 2017). It is specifically adapted for training people with SCI since its 90 kg ballasted keel prevents capsizing. While the boat used has a mainsail and a jib sail on two different masts, we chose to use only the mainsail. The sail is controlled by a sheet and the boat is maneuvered using a joystick located in front of a seat in the cockpit in the center of the boat (Figure 1).

To analyze the effectiveness of learning, we measured the "Velocity Made Good (VMG)," defined as the optimal speed of the boat in relation to the course, expressed in knots. Higher VMG indicated better performance by the sailor. This variable is calculated from the data obtained by a wind instrument (Raymarine®, model ST60; Gandía, Spain) installed on the boat (Figure 2). It consists of a display that presents the direction and speed of the apparent and real wind, measured by a wind vane connected to a cable (E22078) and a "race processor" (Murcia, Spain), all of which are installed on the boat.

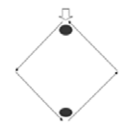
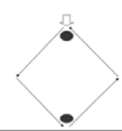
Session	Length/repeat	Maneuvers/actions	Task
Familiarization	30´	Close-hauled / broad reaching course Tacks/gybes pull/push luff up/bear off Parallel tell-tales	Complete a windward-leeward course, making a close-haul course on two boards tacking and then sailing broad reaching course gybing on two boards. 
Pre-test (after one week)	Two laps to the route	2 tacks + 2 gybes	
Acquisition: block practice	8 sessions / 30 minutes per session (Monday, Wednesday, Friday) 3 weeks	15 tacks + 15 gybes (block practice)	Sail on close-haul course (tack) and then on broad reaching course (gybes)
Acquisition: random practice	8 sessions / 30 minutes per session (Monday, Wednesday, Friday) 3 weeks	15 tacks + 15 gybes (random practice)	Navigate by tacking and gybing on each course (close-haul and broad reaching course) in random sequence
Post-test	Two laps to the route	2 tacks + 2 gybes	Complete a windward-leeward course, making a close-haul course on two boards tacking and then sailing broad reaching course gybing. on two boards 
Re-test (after two weeks)			

Figure 3. Sessions, contents, and tasks performed by the research participants during the application of the learning program.

The wind data are collected by the RaceMate software programmed in C++ language (Murcia, Spain) that sampled the data every 3 s from an anemometer (Mastech®, model MS6252A; Greenford, UK) and a Global Positioning System (Garmin®, model Map60; Barcelona, Spain) located on the boat. This device was connected wirelessly to a laptop (Toshiba L455 S5009; Madrid, Spain), powered through a 12 V charger connected to the battery of the inflatable support boat (Valiant, model V-450; Verviers, Belgium), which accompanied the participant at all times. This support boat, which navigated alongside the participants, was used to house the computer recording of the data sampled from the wind equipment and to ensure the safety of the participant in the event of an incident.

2.3. Intervention program

Participants sailed in a learning program under conditions of CI, defined by two practice conditions: (1) blocked practice (three participants) and (2) random practice (four participants). During the blocked practice, each participant performs a fixed sequence and systematically repeated tasks (Figure 3), executing tacking on a close-hauled course (45°–55°) and gybing on a broad reaching course (135°–145°). These two maneuvers were chosen for various reasons: (1) they are the two main maneuvers, whereas the others are considered as auxiliary or modified versions of them; (2) they are the only two maneuvers that can be implemented using a CI protocol independent of weather conditions without affecting navigation and VMG; (3) the execution of all other maneuvers is dependent on wind intensity and direction; (4) it is not possible to control or intentionally modify other sources of CI such as variability of the sailing conditions related to wind strength and direction, the balance of the boat, and the change of board/sideways. Therefore, we refer to reduced interference, rather than low interference, in blocked practice when a sequence of technical actions were repeated

Table 2. Arrangements of all the eight blocked and random practice sessions.

Practice schedule	Weeks	Monday	Wednesday	Friday
Random	First week	Session A: 15 tacks + 15 gybes	Session B: 15 tacks + 15 gybes	Session C: 15 tacks + 15 gybes
	Second week	Session B: 15 tacks + 15 gybes	Session C: 15 tacks + 15 gybes	Session A: 15 tacks + 15 gybes
	Third week	Session C: 15 tacks + 15 gybes	Session A: 15 tacks + 15 gybes	
Blocked	First week	Session A: 15 tacks + 15 gybes	Session A: 15 tacks + 15 gybes	Session A: 15 tacks + 15 gybes
	Second week	Session A: 15 tacks + 15 gybes	Session A: 15 tacks + 15 gybes	Session A: 15 tacks + 15 gybes
	Third week	Session A: 15 tacks + 15 gybes	Session A: 15 tacks + 15 gybes	

In random practice, 30 tacks and gybes were practiced randomly in each session. In blocked practice, 15 tacks were executed, followed by 15 gybes, repeating the same session weekly.

in the handling of the boat, assuming the uncontrollable factors mentioned, and of high interference when such actions are randomized during the handling in random practice of the boat. During the practice in random sequence, the participants executed a sequence, with tacking and gybing maneuvers in the up- and downwind navigation directions, respectively (Figure 3).

The sessions of random practice were incompletely balanced, so that session was never repeated in the same order. The sessions of blocked practice were not balanced, so that each session was repeated in the same order until completing all eight sessions (Table 2). An initial information and feedback protocol was used by the instructor who accompanied the participants on the powerboat. This was designed so that there would be no difference in the information transmitted to the participants in any of the practice sessions so as to ensure adherence to the protocol and no compromise of safety to the participants as well as other users in their vicinity during the experiment. In the levels of initiation to sailing if there is not a minimum of feedback, the boat not only does not sail but also compromises the safety of the participants and those around it.

The feedback given to the participant referred specifically to the control of the wind-measuring equipment and the Global Positioning System located on the boat (Figure 2). The total duration of the learning program, from the familiarization session to the retention test, was 8 weeks. The effectiveness of the execution of the maneuvers was recorded in the familiarization, pre-test, post-test, and retention test.

2.4. Statistical analysis

The Shapiro–Wilk test was used to analyze the distribution of data on wind intensity. A repeated-measures analysis of variance (ANOVA) with Bonferroni post hoc corrections was applied to rule out significant differences in wind intensity between the tests. Effect sizes were estimated with partial eta squared (η_p^2) and Cronbach's α to determine the reliability of the measurement tests. An inter-group ANOVA test was applied to determine whether there were significant differences between the two practice conditions (blocked vs random).

Two techniques suitable for analysis of data in single-case designs were utilized: indices of data overlap (non-overlap of all pairs, NAP; Parker & Vannest, 2009) between phases to estimate the size of learning effect (or the magnitude of change) and Jacobson and Truax's (1991) statistical approach for estimating the significance of the learning effect.

We carried out an intra-subject analysis of VMG data, taking into consideration the differences in practice schedules of each subject as well as the small sample size. The significance of the change in learning rate was evaluated for the familiarization, pre-test, post-test, and retention test conducted 2 weeks after the acquisition phase.

To the apply Jacobson and Truax's (1991) technique, we first established a cut-off point (C) to determine whether a significant change is detected. As a next step in applying this method, we confirmed that the change observed does not reflect the measurement error, but rather represents a reliable change. This confirmation was completed by the application of a Reliable Change Index (RCI), determined by considering the typical difference in error between the results of each test (s_{dif})

$$\begin{aligned} \mathrm{RCI} &= \frac{X_1 - X_2}{S_{dif}} \\ Sdif &= \sqrt{2(\sigma \text{ group})^2} \\ &= \sqrt{2(\sigma \text{ group}\sqrt{1 - \text{Cronbach's } \alpha})^2} \end{aligned} \tag{1}$$

X_2 represents each participant's test result, whole X_1 is the data obtained from the instruments in the previous test. The typical difference of errors between two tests (S_{dif}) describes the distribution amplitude of the change in punctuation that would occur if there was no real change. Cronbach's α denotes the reliability of the internal consistency achieved in the measurement tests. It would be unlikely ($p < .05$) for RCI to be higher than 1.96 without a real change. Therefore, the change in the participants' results needs to exceed this RCI value to show that the observed change does not reflect measurement errors in the test or random effects

Table 3. Results of the test of normality and repeated measures applied on the wind intensity in each of the tests.

	Shapiro–Wilk			Repeated-measures ANOVA		
	Statistical analysis	DF	p	Mean ± SD	p	(η_p^2)
Pre–post test	0.9	7	.5	12.4 (2.0)	1.0	0.4
Post-retention test	0.8	7	.08	11.31 (2.2)	.4	0.4
Pre-retention test	0.9	7	.4	9.11 (2.3)	.2	0.4

DF: degrees of freedom.

Table 4. VMG mean data registered in each participant according to the conditions of practice.

Participant	Practice	Familiarization		Pre-test		Post-test		Retention test	
		Tacking	Gybing	Tacking	Gybing	Tacking	Gybing	Tacking	Gybing
1	Blocked	1.9 (2.0)	3.4 (0.7)	2.5 (2.5)	3.2 (0.6)	1.6 (0.2)	1.9 (0.2)	2.4 (0.8)	2.6 (0.5)
2		1.6 (0.7)	2.0 (0.4)	2.1 (0.6)	2.4 (0.6)	2.3 (0.2)	3.1 (0.6)	2.9 (0.6)	2.5 (0.5)
3		3.3 (0.3)	3.1 (0.2)	2.2 (0.5)	2.5 (0.6)	2.3 (0.5)	2.5 (0.8)	1.5 (0.3)	1.9 (0.2)
4	Random	1.4 (0.6)	2.4 (0.8)	2.2 (0.5)	2.9 (0.6)	2.4 (0.7)	2.9 (0.3)	1.6 (0.3)	1.9 (0.2)
5		2.6 (0.6)	2.9 (0.5)	3.1 (0.8)	3.1 (0.5)	4.8 (1.4)	2.3 (0.5)	1.5 (0.3)	1.7 (0.3)
6		1.7 (0.8)	1.8 (0.4)	2.3 (0.6)	3.2 (0.5)	2.2 (0.3)	2.7 (0.6)	1.1 (0.6)	2.0 (0.4)
7		2.1 (0.9)	2.2 (1.0)	3.0 (0.6)	2.3 (0.5)	2.6 (0.6)	2.7 (0.5)	3.4 (0.2)	3.0 (0.3)

VMG: Velocity Made Good.
Data expressed in knots (mean ± SD).

$$\mathrm{RCI} > 1.96 \rightarrow \frac{X_2 - X_1}{S_{dif}} > 1.96 \rightarrow X_2 - X_1 > S_{dif} \times 1.96 \quad (2)$$

3. Results

Procedures were conducted at wind intensities ranging from 5 to 12 knots with a variance in direction no higher than 5° between the tests and practice, achieving very stable navigation conditions.

The wind intensity exhibited a normal distribution of the data (Table 3). Similarly, we confirmed a lack of significant differences in wind intensity between the measurements taken at different tests, thereby establishing that this variable did not introduce a confounding effect on the results (Table 3).

Based on the information compiled from VMG data, the participants' performance was analyzed with respect to learning (pre-test, post-test, and retention test). Differences were observed in results, depending on the type of practice schedule and the type of skill (tacking/gybing; Table 4).

Inter-group ANOVA test confirmed a lack of significant differences in VMG data ($p > .05$) recorded during the practice of the two types of skills (tacking and gybing) between the measurements taken at different tests, among the participants who practiced on each type of practice schedule.

Table 5 presents the intra-subject values obtained from the analysis of the effectiveness of the learning program (NAP) and the significance of the change (RCI) in the VMG variable. Positive values indicate an increase in the VMG, being significant when they are equal or superior to the RCI (1.96) with $p \leqslant .05$. Conversely, negative values indicate a decrease in the VMG. The effectiveness (NAP) is presented in quartiles, ranging from 25%, which suggests an improvement in a single test, up to 100%, which corresponds to an improvement in all four tests.

3.1. Blocked practice

For participant 1, the blocked practice program was found to be 50% effective when navigating in the tacking course and 25% in the gybing course, with a significant increase in the VMG when comparing the retention test data with the post-test measurement (RCI = 3.08; $p \leqslant .05$; Table 5). This increase was also observed in the same tests performed on the gybing course, although the difference was not found to be significant.

For participant 2, the blocked practice program was found to be 100% effective when navigating in the tacking course and 75% in the gybing course, with the increase in the VMG found to be significant when comparing the pre-test with post-test data in the tacking course (RCI = 2.75; $p \leqslant .05$) and the retention test with post-test data in the gybing course (RCI = 2.11; $p \leqslant .05$; Table 5). A trend-level increase in VMG is also observed in other tests on the tacking and gybing courses (except in the comparison between the post-test

Table 5. Effectiveness of the learning program (NAP) and significance of change (RCI) produced with blocked and random practice sessions.

Practice	Participant	Type of skill	Familiarization vs pre-test	Pre-test vs post-test	Post-test vs retention test	NAP (%)
			RCI ⩾ 1.96 ($p \leqslant .05$)			
Blocked	1	Tacking	1.05	−7.32	3.08[a]	50
		Gybing	−0.62	−4.77	1.94	25
	2	Tacking	0.85	1.37	2.11[a]	100
		Gybing	0.73	2.75[a]	−1.49	75
	3	Tacking	−1.90	0.74	−2.84	25
		Gybing	−1.45	0.25	−1.64	25
Random	4	Tacking	2.36	0.58	−0.93	50
		Gybing	1.62	−0.16	−5.78	25
	5	Tacking	1.54	6.28[a]	−4.22	50
		Gybing	0.89	−3.22	−3.38	25
	6	Tacking	2.05	−0.26	−1.46	25
		Gybing	5.06	−2.13	−4.59	25
	7	Tacking	2.62	−1.33	1.11	75
		Gybing	0.34	1.59	1.66	100

Cronbach's α = 0.8. NAP = non-overlap of all pairs; RCI = Reliable Change Index.
[a]Significant change (RCI ⩾ 1.96; $p \leqslant .05$).

with the retention test in the gybing course), although these do not become significant; Table 5).

For participant 3, the blocked practice program was only 25% effective when navigating in the tacking and gybing courses, with no significant increases in the VMG in any of the tests (Table 5). Conversely, decreases in VMG values during the navigation in both tacking and gybing courses were observed when comparing the familiarization test with the pre-test and between the post-test and the retention test, and between the pre-test and the retention test, as well as on the gybing course (except in the comparison of the post-test with retention test in this last section), although these do not become significant; Table 5).

3.2. Random practice

For participant number 4, the random practice program is only 50% effective when navigating on the tacking course and 25% effective on the gybing course, with no significant increases in VMG observed between any of the tests (Table 5). Increases in VMG were observed during the navigation on the tacking course when comparing the familiarization test with the pre-test, and between the pre-test and the post-test. Conversely, VMG was found to decrease between the post-test and retention test. However, none of these cases exhibited statistically significant differences. In the gybing course, there is an increase in VMG between familiarization and pre-test and decreases in the rest of the tests, although none of the differences were found to be significant (Table 5).

Data acquired from participant 5 showed the random practice to have been 50% effective when navigating on the tacking course and 25% effective on the broad reach course, with significant increases in the VMG between the pre-test and post-test (RCI = 6.28; $p \leqslant .05$) on the tacking course (Table 3). An increase in the VMG is also observed between the familiarization and the pre-test on the tacking and gybing courses, although it does not reach significance in either of the two cases (Table 3). On the other hand, non-significant decreases were observed with the random practice approach in other tests, on both the tacking and broad reach courses (Table 5).

In analyzing the data from participant 6, the random practice was 25% effective when sailing on the tacking course and 25% effective on the gybing course. Increase in VMG values was observed between the familiarization and the pre-test on the tacking and broad reach courses, which were found not to be statistically significant (Table 5). In other tests, this practice condition resulted in trend-level decreases in VMG values on both navigation courses (Table 5).

For participant 7, random practice was found to be 75% effective when sailing on the tacking course and 100% effective on the gybing course. This particular participant exhibited increased VMG in all the tests, except when comparing the results of the pre-test with those of the post-test in the tacking course. These increases were found not to be statistically significant.

4. Discussion

This study evaluated the effectiveness of a learning program adapted to people with SCI applying CI. Training outcomes were evaluated in the ability to perform tacking and gybing, two fundamental maneuvers used in controlling the boat. In analyzing the results and taking previous studies into consideration, the effects of CI on motor learning should be interpreted with caution, given the variability in the data generated in the conducted research (Graser et al., 2019). The complexity of applying this type of practice programs in populations with SCI with varying levels of damage becomes very evident, since the effects elicited are dramatically different. Its applications are further complicated by the performance of protocols in unstable environments, such as the sea. Therefore, as stated by Merbah and Meulemans (2011), a universal practice schedule cannot be applied in every different context and for all types of people.

Assessing the effectiveness of the learning program, we observed a tendency toward an increase in VMG in both random and blocked practice conditions on all participants. This result suggests that improvements in boat handling can be achieved by practice, regardless of whether it is carried out in conditions of high or low CI. Contrary to our expectations, in general, it does not seem that learning under random practice is more effective than learning through blocked practice. This apparently beneficial effect generated by both practice conditions was also observed by Cheong et al. (2016), who demonstrated similar effects in evaluation of the learning of hockey skills. This finding corresponds to the fact that, in more ecological investigations and with more complex sports tasks, it is difficult to generate optimal conditions which would allow high CI to produce the expected superior effects compared to blocked practice (Merbah & Meulemans, 2011). This equality of results between both practice conditions has also been observed in laboratory experiments, such as Pollatou et al. (1997), on learning of throwing and kicking tasks; Granda-Vera et al. (2008), when the effect of CI was analyzing on throwing task in 6-year-old children; Zetou et al. (2007) in learning volleyball skills; and Travlos (2010) in volleyball serve. In these studies, there were no significant differences between the two schedules' practice. Among the multiple reasons that have been described that can explain the absence of differences, those related to the development of research in ecological contexts and motor skills practiced in real life have been highlighted. This fact would make the variability present in the environment a factor that could alter the superior effects of blocked practice in periods of acquisition, requiring longer periods of practice to observe such effects (Barreiros et al., 2007).

With regard to the results evaluated by test, it should be noted that all participants, except for 1 and 3, seem to increase the effectiveness of the handling of the boat after the familiarization period, in which all practiced the blocked practice and the two maneuvers. Participant 1 reduced his effectiveness in gybing and participant 3 in the two maneuvers practiced. Although these results are not significant, this suggests that the blocked practice used in the familiarization sessions for all participants and maneuvers may have been effective.

With respect to the results recorded in the post-test, participant 1 who practiced en bloc reduced the effectiveness, while participants 2 and 3 increased it. However, all the participants who learned to sail by random practice reduced the effectiveness in the handling of the boat, in both maneuvers, like participant 6, in the tacking course like participant 7, or in the gybing course like participants 4 and 5. These results seem to coincide in part with those observed in previous studies, regarding the benefits of blocked practice in initial periods of learning and decreases in motor skill performance, fostered by random practice after such a period of practice. Bertollo et al. (2010) found similar effects when analyzing the effects of CI in the learning of rhythmic dance step sequences in adolescents.

In the same way, Rendell et al. (2011) found similar results. By applying CI to the learning of ball striking and handball tasks in young adults with little experience, they also detected that high CI impairs or reduces the acquisition in these skills. It is necessary to indicate that the putative superior effect of blocked practice may be a reflection of the conditions of the tests, since they were designed on the basis of the suggestions of Magill (2011) and Broadbent et al. (2015), who proposed that the real conditions of practice should be simulated and transfer tests were performed to analyze the effects of CI. Therefore, the practices of the tack and the gybe tasks were implemented in blocks, despite the fact that this design moves away from the real navigation conditions and, as mentioned previously, is strongly affected by the variability in the control of the boat. We considered this approach to be the only acceptable way to control the learning variables. Our findings should be verified by assessing whether same results can be obtained in a more complex test with more weight given to the motor response capacity of the navigator during a tour as it happens in real navigation conditions. It is possible that once this phase of learning basic navigational motor responses (keeping the course within acceptable margins, turning, and gybing) has been overcome, the differences between blocked and random practices will become more apparent in favor of random practice.

However, our results differ from previous results. Porter and Magill (2010), in a study on putting a golf ball and basketball passes, concluded that a practice schedule offering systematic increases in CI facilitates skill learning. Feghhi and Valizade (2011) came to the same conclusion in free-throw basketball. To explain this difference in results, several aspects should be taken into account, such as the (1) ecological validity and complexity of the task as a result of practice in an unstable environment with multiple DOF and (2) as we have already pointed out, the heterogeneousness of the trainees, conditioned by their injury and the degree of affectation, can affect their ability during navigation.

The research carried out by these authors investigated the effects of CI on simple motor skills, while tacking and gybing, together with the instability of the sea and the mobility restrictions of SCIs, represent a high level of complexity. Thus, the blocked practice with reduced CI, in which the DOF (complexity and exigency in the execution of the maneuvers) are reduced, may have provided a greater benefit than the random practice in our participants at the end of the acquisition period.

An interpretation of reported results could be based on the findings of Jones and French (2007) and Zetou et al. (2007) which suggest that the complexity of sports skills practiced is a key factor reducing the effects of CI. Other authors, such as Merbah and Meulemans (2011), also proposed that the inherent overload of practice in real environments may be a limiting factor in achieving the beneficial effects of CI. In fact, it seems that an already complex task, such as the handling of a sailboat in performing the tack or gybe, can become too complex during the learning process. In our case, the increased DOF derived from practicing both maneuvers in a random way in the open sea may provide an excessive cognitive and motor load for a population without a high level of expertise (Guadagnoli et al., 1999; Hebert et al., 1996) and limited mobility associated with SCI. The literature review performed by Graser et al. (2019) did not suggest the great difficulty in making generalizations in the results of these studies, due to the great heterogeneity of the participants, the proposed motor tasks, and the context inside or outside the laboratory, all of which are present in this and many other studies as the authors state. As we have already pointed out, it is possible that once this learning phase is over, the effect of CI will be amplified into more complex sailing skills (more precise course adjustments or maneuvers more in line with wind variability) taken autonomously by the participant.

With regard to the results of retention, the blocked practice of participants 1 and 2, in this case only in the tacking course and being non-significant, gives them greater effectiveness after 2 weeks without practice. With regard to the random practice after this period, the only beneficiary is participant 7. All other participants reduce their ability to handle the boat. The results, except for participants 1 and 7, seem to indicate that both random and blocked practice conditions can bring decreases in the effectiveness of boat handling after periods of no practice. In this sense, recent stages, such as Jo et al. (2020), carried out in patients with stroke also found no difference between the two practice conditions.

Again, analysis of these results should consider the complexity of the task associated with the context and the ability of the learners, conditioned by their injury and the degree of impairment. In this study, the 2 weeks without sailing have crucially conditioned the ability to handle the boat. Not even randomized practice, which would allow, according to the studies discussed, a longer performance over time has generated this benefit. This suggests that the tasks are so complex and the participants' ability to handle the boat is so reduced that the simple fact of not practicing already causes a decrease in performance, which is independent of the schedule practice. The lack of difference between blocked and random practices and the loss of performance in the retention test were expected due to the great heterogeneity and the instability of the sea environment (Graser et al., 2019). In this regard, it may be interesting what Hebert et al. (1996) and Brady (2004) indicated, the complexity of applying CI in ecological situations may require more time to control the skill, a fact that would cause the absence of differences between blocked and random practices that is seen in the retention tests of our study.

5. Conclusion

This study describes a pioneering approach to the learning of sailing sport for people with SCI. The proposed learning protocol used an adapted boat, recording the trainee's performance through wind equipment, and providing continuous support from an inflatable boat during the practice in open waters, highlighting the complexity of the performed work.

No significant differences have been found in learning the two boat handling skills between types of practice. This result could be due to the heterogeneity of the participants, the size of the sample, and the instability of the sea environment. For these reasons, a single-case analysis is necessary, which can explain the behavior seen in the participants during the learning process.

In this respect, results that have been presented to analyze data in these single-case designs and assess the magnitude and significance of boat control techniques do not provide the necessary key to understanding the factor responsible for these changes. According to the contributions of Sanz and García-Vera (2015), the causal conclusions about whether learning program is responsible for changes are based more on the design features of a single-case study than on obtaining a large significant change or even a statistically significant change.

This study demonstrates the suitability of applying CI to facilitate skill acquisition in people with SCIs learning to sail dinghies, since all participants (regardless of the amount of CI and the level of injury) have achieved an increase in their initial capacity to manage the boat. Therefore, further applications in the practice of sailing should be pursued in the future, with additional work aimed to further increase the ability of the navigator to adapt. Once the initial stages of learning to sail are over, the effect of CI could be increased toward random practice when the skills require greater autonomy and adjustment to the wind by the participant.

Finally, this study highlights the need to pursue this line of research further, since it presents a double benefit to the patients with SCIs. On one hand, such training facilitates the processes of social inclusion and normalization for people with SCI, with the potential for applying this type of program to other similar populations. On the other hand, presented work has increased the understanding of the effects of CI in a sport environment under a paradigm that has not been evaluated before, that is, the practice of sailing in open waters by individuals with SCI.

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Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethics approval

The research was approved by the Ethics Committee of the Catholic University of Murcia (Spain). We certify that all applicable institutional and governmental regulations concerning the ethical use of human volunteers were followed during the course of this research.

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Ruperto Menayo, PhD (Teacher Training College, University of Extremadura, Cáceres, Spain), since the beginning of his professional career in 2004, he has worked in the lines of research within the area of "Control and motor learning in physical activities and sports." The research carried out on this topic has focused on the following specific aspects: (1) design of protocols for the measurement of control and motor learning, (2) study and analysis of the visual behavior of athletes, (3) analysis of the effect of the induced variability in the control of human movement, (4) analysis of the organization of practice in learning motor skills, (5) description of human movement under the paradigm of complex dynamic systems. He has been the leader of different research projects financed in the area of control and motor learning. He has published articles in the area of motor learning and control, in journals of national and international impact on these topics. Based on these lines of research, he has directed several doctoral theses related to motor control and learning on different perspectives. Currently, he has expanded his work to the training of teachers in sports and physical education.

María Felicia Egea is PhD Student (Sports Faculty, San Antonio Catholic University, Murcia, Spain) in sports science from the Sport Faculty of the UCAM of Murcia. The research line developed is related to the adapted sail and specifically to motor control and sailors with spinal cord injury. Her work has been carried out in the "Aula del Mar Laboratory" at the UCAM Sports Faculty, training as an expert in the use of sailing simulator. She has worked as a national coach with adapted sailing teams with good results in international competitions. She has a long experience as a sailor and coach in different types of navigation. She has worked in different sports associations such as Association of People with Spinal Injury and Other Physical Disabilities (ASPAYM) at the regional level or TAMBIEN Foundation (sport adapted for the inclusion of people with disabilities), at the national level, always related to adapted sailing.

Aarón Manzanares, PhD (Faculty of Sport, San Antonio Catholic University, Murcia, Spain), since the start of his PhD in 2011, the line of research he has worked on over the last 8 years began and has focused on the study of "Determinants of performance in sport sailing: visual behavior and competitive anxiety." The research carried out on this topic has focused on three specific aspects: (1) design of a protocol to evaluate the determining factors of performance in sailors, through a partially inverse sail simulator; (2) study and analysis of the visual behavior of sailors in training categories in relation to different variables, such as experience, age, and training hours; (3) analysis of the relationship between pre-competitive anxiety and factors related to pre-competitive eating and the morphology of sailors at the age of sporting initiation. Based on these lines of research, he has made stays at the University of Melbourne and the University of Tasmania (Australia), to collaborate in the design and research on simulated navigation. From this research, collaboration with international sailing federations (Royal Spanish Sailing Federation and Norwegian Sailing Federation) has emerged, through the evaluation of the performance of Olympic-level sailors in a sailing simulator. He is currently developing a project for adapted sailing for people with spinal cord injuries in collaboration with the National Paraplegic Hospital in Toledo. In this line of research, a European Erasmus + project (EU co-funding), called "Sailing for physical disable people," has been awarded. He has published in journals of national and international impact on these topics.

Francisco Segado, PhD (Sports Faculty, San Antonio Catholic University. Murcia, Spain), since 2010, has been director of the "Aula del Mar Laboratory" at the UCAM Sports Faculty and director of various doctoral theses related to sports sailing from different perspectives, such as the visual search strategy for young sailors, motor control, high performance of sailors or the management of sailing schools. He develops different collaboration agreements with national sailing federations such as the Spanish Sailing Federation or the Norwegian Sailing Federation. He is currently the main researcher of different sailing projects as a teaching innovation in the teaching and learning of sailing. Teaching for Understanding in Sailing or European Erasmus + project (EU co-funding), called "Sailing for physical disable people," has been awarded. He has published in different impact journals with topics related to sailing.