

ARTICLE

Rate of concurrent augmented auditory feedback in postural control learning in adolescents

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Abstract - Introduction: The main objective of this study was to determine the rate of auditory concurrent feedback that best enhanced the learning of a continuous postural task in adolescents. **Material and methods:** A sample of thirty adolescents (13 to 14-years old) was used, who were assigned to three groups: i) control group (CG); ii) 100% auditory feedback group and iii) 67% auditory feedback group. The subjects performed a pre-test, practice, post-test and a retention (24 hours after the practice). In the postural control task subjects were instructed to remain on a seesaw (unstable in anteroposterior position) and keeping it as level as possible. **Results:** The results demonstrated that concurrent auditory feedback did not enhance the performance of the continuous postural task, although concurrent auditory feedback (both 100% and 67% rates) caused changes to the postural control strategies. **Conclusions:** From this it was concluded that 100% and 67% concurrent auditory feedback are more recommendable than no-feedback in adolescents' postural control learning.

Keywords: knowledge of results, balance, motor learning

Résumé - Influence du taux de feedback auditif sur l'apprentissage d'une tâche posturale chez l'adolescent. Introduction: L'objectif principal de cette étude était de déterminer le taux de feedback auditif qui améliore le mieux l'apprentissage d'une tâche posturale chez des adolescents. **Matériel et méthodes:** Trente adolescents âgés de 13 à 14 ans ont participé à cette étude et ont été répartis en trois groupes: i) un groupe contrôle (CG), ii) un groupe avec feedback auditif à 100 % et iii) un groupe avec feedback auditif à 67 %. Les participants ont réalisé successivement un pré-test, un entraînement à la tâche posturale, un post-test et un test de rétention. La tâche de contrôle postural consistait à tenir debout sur un plateau instable (instabilité antéro-postérieure) et à conserver le plateau aussi horizontal que possible. **Résultats:** Les résultats ont mis en évidence que le feedback auditif, pendant la tâche posturale, n'améliorait pas la performance de la tâche posturale, bien que les rétroactions auditives (à des taux de 100 % et 67 %) aient entraîné des changements de stratégies de contrôle postural. **Conclusions:** Des feedback donnés à 100 % ou 67 % des essais semblent bénéfiques comparé à l'absence de feedback auditif dans l'apprentissage du contrôle postural chez les adolescents.

Mots clés : connaissance du résultat, équilibre, apprentissage moteur

1 Introduction

Feedback information is considered an important element in motor learning and has been used to enhance postural control and reduce postural sway (Lakhani & Mansfield, 2015; Zijlstra, Mancini, Chiari, & Zijlstra, 2010).

Nevertheless, there are some published findings that are not consistent and do not recommend feedback to enhance motor performance (Faugloire, Bardy, Merhi, & Stoffregen, 2005). The use of feedback to improve postural stability has now been revived because of the recent advances in technology (Dozza, Chiari, Peterka, Wall, & Horak, 2011). The research in this field has included questions about the best types of feedback to present the information

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to the learner or what kind of feedback is the most effective in learning motor skills (Konttinen, Mononen, Viitasalo, & Mets, 2004).

Overall, feedback strategies may be classified according to three factors: the point in time when feedback is provided; the source of the information given and the sensory channel through which it is provided. Thus, there is both concurrent (*i.e.*, information which is provided during motor task execution) and terminal feedback (*i.e.*, information is provided once the task is finished) if we attend to the point in time. Regarding the source of information, intrinsic feedback refers to the sensory afferences informing about the movement performed, while extrinsic or augmented feedback may be described as the information which cannot be provided without an external source (Sigrist, Rauter, Riener, & Wolf, 2013a). There are two types of augmented feedback: knowledge of results and knowledge of performance. Knowledge of results refers to the information about the outcome of a movement, while knowledge of performance refers to extrinsic information that is generated by an external source about the actual action pattern of a movement (Fujii, Lulic, & Chen, 2016; Konttinen, *et al.*, 2004). Finally, there is visual, auditory and haptic feedback, if we refer to the sensory channel involved (Sigrist, *et al.*, 2013a). The combination of such settings produces multiple feedback types, which should be studied in order to determine the most effective type of feedback in motor learning, according to the subject's age and the difficulty of the task.

Another point of interest is which feedback should be provided to facilitate retention (Fujii, *et al.*, 2016). Some studies support the guidance hypothesis, which postulates that too much feedback is detrimental to motor skill learning (Schmidt, Young, Swinnen, & Shapiro, 1989; Sparrow & Summers, 1992; Weeks & Kordus, 1998; Winstein & Schmidt, 1990; Wulf & Schmidt, 1989). This is due to three reasons: first, the learner comes to rely on augmented feedback at the expense of his/her own intrinsic feedback. Second, reduced rate of feedback may help the learner to use his/her intrinsic feedback and, third, frequent augmented feedback may also increase movement variability (Fujii *et al.*, 2016). To test this hypothesis, recent research has studied the effects of feedback rate on motor learning in children and adults. It should be pointed out that children and adults are somewhat different, because children use different strategies to adults when processing information in tasks that require visuospatial working memory, object recognition memory, verbal learning, copying spatial patterns or higher-level attention focusing (Sullivan, Kantak, & Burtner, 2008).

Some previous studies have found that reduced knowledge of results feedback is more effective in motor learning of a simple task than 100% knowledge of results feedback in adults (Sparrow & Summers, 1992; Sullivan, *et al.*, 2008; Winstein & Schmidt, 1990; Wulf & Schmidt, 1989). Nevertheless, other authors have found no differences between 100% and reduced knowledge of results

feedback in a simple task learning in adults (Dunham & Mueller, 1993; Lai & Shea, 1998; Sparrow, 1995; Wishart & Lee, 1997). In view of these contradictory results, this research field needs further consideration by the scientific community. Finally, 100% feedback has been found most effective in motor learning of complex task in adults (Wulf, Shea, & Matschiner, 1998). Therefore, the type of the task (rather than the learner's age) could be an important factor in determining the optimal rate of the feedback to enhance motor learning.

Regarding children and adolescents, Sullivan *et al.* (2008) showed that learners who received 100% visual feedback (knowledge of results) during the acquisition phase were more accurate and consistent in a delayed retention test of a simple task than children who received reduced visual feedback schedule (62% feedback). On the other hand, Weeks & Kordus (1998) found that children who received reduced knowledge of performance (33%) were superior to children who received 100% knowledge of performance for developing and maintaining a prescribed form in a soccer throw. This disagreement may be due to the differences in the type of feedback used by the different authors (*i.e.*, knowledge of results *vs.* knowledge of performance). Finally, Wulf, Chiviawosky, Schiller, & Ávila (2010) found 100% terminal feedback about the knowledge of the performance with an external focus of attention was more effective in enhancing the learning of a soccer throw than reduced feedback (33%) with an external focus of attention. However, when the focus of attention was internal, no differences were found between reduced and 100% feedback, and the mean value of the transfer test higher was in the 33% feedback group. It would thus seem that 33% feedback is more effective when knowledge of performance using an internal focus of attention is provided, although when the knowledge of performance is reported using an external focus of attention, 100% feedback is more effective. Various factors (*e.g.*, age, task characteristics, type of feedback) have been found to affect the most effective feedback rate for motor learning. The number of works carried out to date in which feedback is used as a tool to improve motor learning in children or adolescents is strongly lower than those whose study population is adults (Sullivan, *et al.*, 2008). Moreover, the fraction of the literature focused on the effect of the use auditory feedback on motor learning in adolescents is almost non-existent. Furthermore, studies that apply auditory feedback generally do not focus on postural control as the skill to improve, and those that do it, as in the case of Marco-Ahulló, García-Massó, García-Osa, & Estevan (2019), use terminal auditory feedback (*i.e.*, subjects are not receiving information during the practice of the task). For these reasons, this research topic needs further studies to develop a complete landscape of the optimal feedback rate, depending on task, learner and feedback characteristics. The main objective of this study was thus to determine the rate of auditory knowledge of results concurrent feedback that enhanced the learning of a continuous postural task in adolescents. In line with Sullivan *et al.* (2008) with visual feedback, in the current

study with auditory feedback, our hypothesis was that adolescents who received 100% feedback would show higher performance in the retention test of the motor task than adolescents that received reduced auditory feedback (67%). It should be pointed out that concurrent visual feedback may interfere with a motor task that depends on the visually perceived information. This may overload the learner due to his attention being focused on the environment and the feedback information at the same time. To minimize perceptual overload, concurrent feedback could also be provided acoustically (Sigrist, *et al.*, 2013a). Auditory feedback could be less interfering and distracting because it does not need a specific focus on the display and a specific orientation of the head in space (Sigrist, Rauter, Riemer, & Wolf, 2013b). For these reason, and because the motor task used required visual sensory information, auditory feedback was chosen in the design of the present study.

2 Material and methods

2.1 Participants

Thirty 13–14-year-old secondary school students participated in the study. A sample size calculation was performed prior to recruitment using G*Power 3.1 (University of Düsseldorf, Düsseldorf, Germany). A Cohen's effect size of $d = 1.33$ was used for the calculation [based on data published previously (Sullivan, *et al.*, 2008)], the level of significance was set at 0.05 and the statistical power at 0.95. The results of this analysis reported a sample size of $n = 10$ in each group. Subjects were randomly assigned to three groups, with the restriction that group sizes be equivalent ($n = 10$) and that each group contain an equal number of boys and girls. These three groups were: i) control group (CG); ii) 100% auditory feedback group and iii) 67% auditory feedback group. The following inclusion criteria were used: i) between 13 and 14 years old (both inclusive); ii) no injuries in the last 6 months; iii) no neurologic or musculoskeletal disorders that could affect balance control. The participants' characteristics are shown in Table 1.

Previous approval was obtained from the Institutional Review Board of the University of Valencia. Also, the parents of the participants supplied written informed consent before participating in the experiment.

2.2 Procedure and feedback

The participants attended the laboratory on two consecutive days to complete a series of standing balance tasks. During the first day, they carried out the pre-test (3 trials), practice (12 trials) and post-test (3 trials). The retention (3 trials) was performed next day. Pre-test, post-test and retention consisted of 3 trials in a bipedal standing position on a seesaw, with arms relaxed and without feedback. Each trial lasted 30 seconds with 30–60 seconds of rest in between. This protocol was the same in all groups. The feet were placed in the standardized foot

Table 1. Subjects' characteristics.

Variable	CG	100% feedback	67% feedback
Sex			
Male	5	5	5
Female	5	5	5
Age (years)	13.3 (0.48)	13.5 (0.53)	13.4 (0.52)
Mass (kg)	59.33 (9.52)	61.56 (13.78)	60.76 (16.18)
Height (m)	1.67 (0.07)	1.65 (0.09)	1.65 (0.08)
BMI ($\text{kg} \cdot \text{m}^{-2}$)	21.29 (3.55)	22.56 (3.62)	22.15 (4.33)
BMI _{Percentile}	65.9 (26.76)	74.5 (21.5)	69.2 (24.25)

Data are expressed as mean (standard deviation). BMI = body mass index.

position (with shoulder distance between them) during all the test and practice trials. The customized seesaw (radius = 486 mm) was designed to produce antero-posterior (AP) instability and the participants were asked to keep the device as horizontal as possible. A reference point was placed on the wall 1.5 m in front of the subjects during the tests.

To measure the performance of the task, a Wii Balance Board (WBB) was placed in the middle of the seesaw. With this experimental setting, the position of the centre of pressures (CoP) was proportional to the seesaw angle. This device has been validated as a good means of acquiring CoP signals in studies on both adults (Clark, *et al.*, 2010; Park & Lee, 2014) and children (Larsen, Jørgensen, Junge, Juul-Kristensen, & Wedderkopp, 2014). Raw data was acquired using WiiLab software (University of Colorado Boulder, Colorado, USA) for Matlab R2008a (Mathworks Inc, Natick, USA). Data signals were recorded at a frequency of 40 Hz.

With regard to the practice, the CG carried out 12 trials with the same conditions as the pre-test, post-test and retention (*i.e.*, without feedback). However, the feedback groups received concurrent feedback during all (*i.e.*, 100% feedback) or 2 out of 3 trials (*i.e.*, 67% feedback) of the practice trials. The auditory feedback was provided by two speakers, one situated in front of the subject and another behind. The sound from the front speaker indicated anterior displacement of the CoP, while that from the rear speaker indicated posterior displacement of the CoP. As a consequence, the speakers were silent at the point 0 of the CoP in the AP direction (*i.e.*, when the seesaw was horizontal). The speaker volume increased with increased CoP displacement.

2.3 Data analysis

CoP displacement signals in the AP direction were filtered digitally using a Butterworth low-pass filter with a 12 Hz cut-off frequency. The performance of the task was

assessed using the time of stability (ToS), *i.e.*, the percentage of time in which adolescents remained inside the ± 2.5 mm area in the AP direction. Sway frequency was analysed computing the median frequency of the power spectral density. The median frequency represents the median value of the frequency at which postural corrections are performed (McNevin, Shea, & Wulf, 2003). The higher the median frequency, the higher the number of postural corrections needed to perform the task. The power spectral density was computed by means of the “periodogram” function using a square window without overlap.

We performed a validation of the CoP data provided by the WBB with regard seesaw angle in our laboratory. This validation was performed by means of an accelerometer (using gravity to compute the seesaw angle) as gold standard. Twelve trials (without feedback and maintaining the same characteristics explained in procedures section) were performed and ToS as well as median frequency were computed in the signals obtained by the WBB and the accelerometer. The correlation coefficients between them were $r=0.95-0.99$ for ToS and median frequency respectively.

2.4 Statistical analysis

Statistical analysis was performed using SPSS software Version 21 (SPSS Inc., Chicago, IL, USA). As the Shapiro-Wilk test reported that some variables did not pass the normality assumption, non-parametric tests were used. Standard statistical methods were used to compute the median and interquartile range. Three Friedman’s Anovas were then applied to determine, in each group, the effect of practice on postural task learning. The follow up was performed by Wilcoxon signed rank tests with Bonferroni correction. Significance level was set at $p < 0.05$ in all the statistical analyses.

3 Results

The overall mean ToS and median frequency (considering all groups and testing times) were 68.73 (53.63)% and 0.39 (0.11) Hz, respectively. Figure 1 shows the values of postural control variables in each group during pre-test, post-test and retention. There were no significant differences between the groups in any testing time or variable.

Regarding median frequency, an effect of practice was found in the CG ($\chi^2_2 = 6.8$; $p = 0.03$), 100% feedback group ($\chi^2_2 = 9.9$; $p = 0.007$) and 67% feedback group ($\chi^2_2 = 9.9$; $p = 0.007$). Pairwise comparisons revealed that both 100% feedback and 67% feedback groups showed lower median frequency in post-test and retention than in the pre-test. Nevertheless, the CG showed lower median frequency in the post-test than in the pre-test, but no differences were found between the pre-test and retention.

Finally, there was no significant effect of the practice on the ToS, either in the CG ($\chi^2_2 = 1.56$; $p = 0.46$), the 100% feedback group ($\chi^2_2 = 2.4$; $p = 0.3$) or the 67% feedback group ($\chi^2_2 = 2.89$; $p = 0.24$).

4 Discussion

The main objective of this study was to determine the rate of auditory concurrent knowledge of result feedback that enhanced the learning of a continuous postural task in adolescents. Regarding the performance of the task (*i.e.*, ToS), we did not find significant improvements between pre-test and post-test or between pre-test and retention in any of the three groups, CG, 100% feedback and 67% feedback (Fig. 1), unlike most other studies, which found significant performance improvements (Dunham & Mueller, 1993; Fujii, *et al.*, 2016; Lai & Shea, 1998; Sparrow, 1995; Sparrow & Summers, 1992; Sullivan, *et al.*, 2008; Winstein & Schmidt, 1990; Wishart & Lee, 1997; Wulf & Schmidt, 1989; Wulf, *et al.*, 1998, 2010). Nevertheless, these studies used other performance variables and none used concurrent auditory feedback with adolescents. This could indicate that auditory concurrent feedback would produce different effects than visual feedback in learning a continuous postural task in adolescents.

There are two main reasons for this lack of enhancement of the task performance: i) the short practice period used in this study and/or ii) auditory concurrent feedback is less efficient than other types of feedback in motor learning in adolescents. Sullivan *et al.* (2008) showed that a single arm movement task training of 200 trials using 100% delayed visual feedback was effective in improving task performance in retention in children. Weeks & Kordus (1998) found that reduced (33%) knowledge of performance feedback applied during a practice session of 30 acquisition trials enhanced soccer throw in children. In these two studies, the acquisition phase had more trials than the practice session in the present study, although our task had a duration of 30 seconds and the tasks in these two studies were shorter (between 1–2 seconds). Thus, both the type of feedback and the duration of the practice could explain the differences obtained between the results in previous studies in the field (Sullivan, *et al.*, 2008; Weeks & Kordus, 1998) and the current study.

Moreover, significant reductions of the median frequency of displacement were found in all three groups: the 100% feedback group and 67% feedback group showed a reduction of median frequency comparing pre-test with post-test and pre-test with retention, while the control group only showed significant reductions between pre-test and post-test. Wulf *et al.* (1998) found a frequency reduction due to practice with a ski simulator in young adults that received 100% feedback. As they suggested, this frequency of movement reduction indicates that the subjects performed fewer movement cycles each second, which, together with a higher movement amplitude, was representative of a performance enhancement of ski movement. In our case, the median frequency reductions mean that subjects move with a lower frequency and consequently fewer readjustments than in the pre-test. This means that the subjects in feedback groups change their postural control strategy (*i.e.* the manner in which the subjects use their body to carry out the task) for a more efficient one, since they maintain the same performance

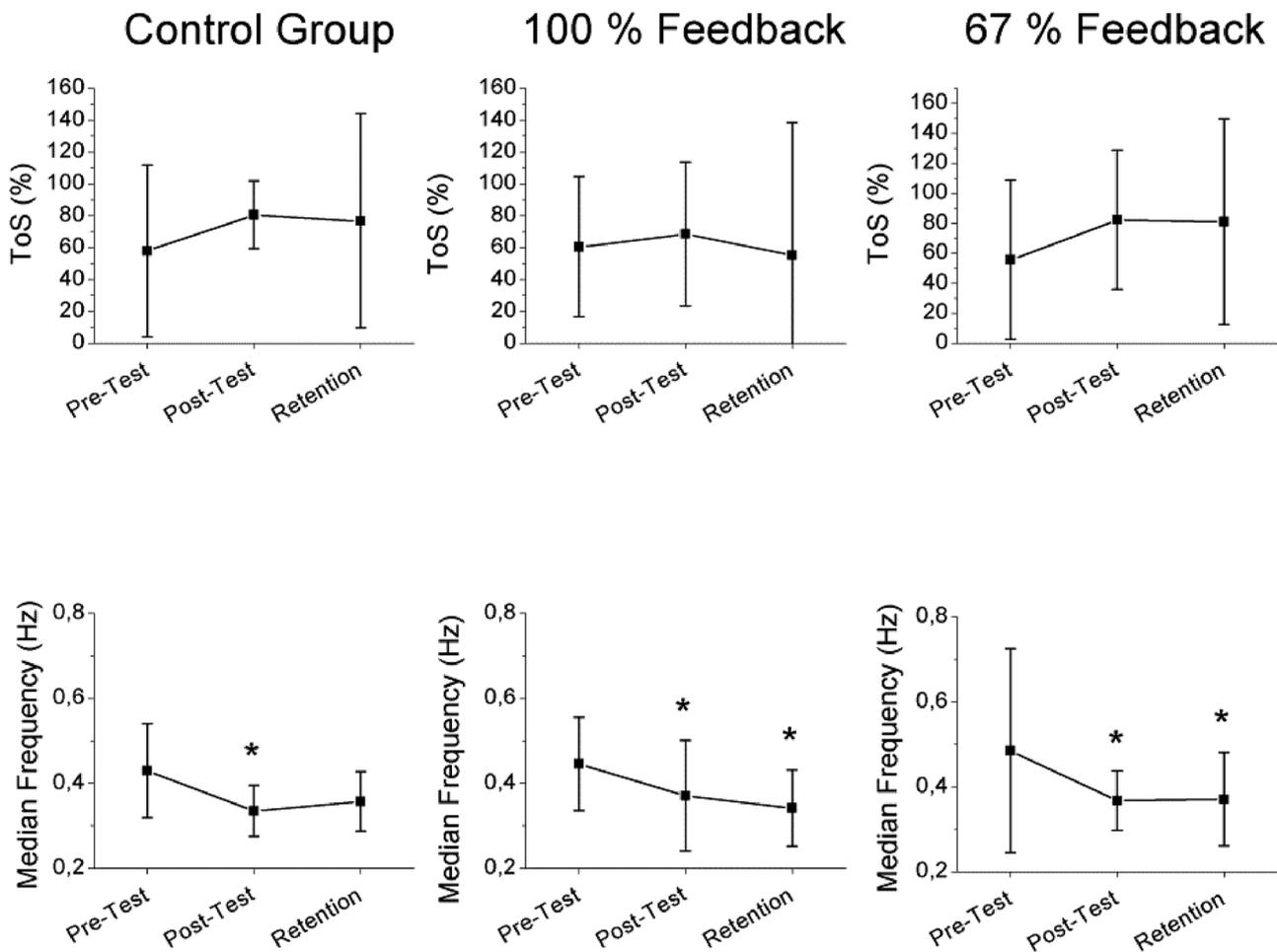


Fig. 1. Effect of practice on Time of Stability (ToS) and median frequency of center of pressure signals.

while reducing the frequency of the postural corrections. It is possible that subject training with feedback learned that when the error is small they should not perform corrections because the movement generated can produce a greater error instead a reduction of it. Therefore, they could learn to change their position only when the seesaw inclination exceeded a self-selected threshold. McNevin *et al.* (2003) showed another study centred in the improvement of postural control, and uses also the frequency of displacements as variable to measure the task performance and their interpretation of median frequency results are totally opposite to ours. The main reason of this is that McNevin *et al.* (2003) used a different task and instruments (*i.e.* a stabilometer unstable in medio-lateral position) to improve the postural control. In this case, perform a great number of adjustments can be synonym of better performance, because contrary to that happens with our instrument, the natural position of the stabilometer is the imbalance, and has a very small range of stability, being almost uncontrollable outside this, therefore it is necessary to make many small corrections to achieve the goal of keeping the platform as level as possible.

With regard to the limitations of this study, it should be noted that although a sample size calculation was

performed, the sample was rather small, with only 10 subjects in each group. This could have affected our results, considering that a bigger sample would have provided more interesting results. In addition, the intervention phase was very short, with only 21 trials (considering practice and testing) organized on two consecutive days. Both the small sample size and short intervention phase could have had an effect on our results, as it is necessary to study the effectiveness of this kind of feedback with a bigger sample and a longer intervention phase. However, if our results are confirmed with a larger sample, our findings on the use of auditory feedback for improvement in postural control tasks can be of great importance, as with short periods of practice significant improvements can be found.

Our results could be useful to physical education teachers and coaches, who often have to provide information to learners and athletes about the errors and achievements made in a performance task event, though many teachers do not use any type of augmented feedback (Tan, 1996). The feedback used in physical education classes is usually verbal, through positive, nonspecific evaluations with reference to whole movement or sport skill (Silverman, 1991). Providing relevant feedback

information is regarded as a key aspect of effective learning (Rink & Hall, 2008). Thus, using other types of augmented feedback (visual, auditory, etc.), which provide more specific information, could mean an important advance in physical education classes and also an increase in the learner's motivation (Viciano, Cervelló, Ramírez, San-Matías, & Requena, 2010). As we have seen previously, auditory feedback could be a way of providing augmented feedback in physical education classes in order to increase the pupils' learning. In addition, these findings can be used by other physical activity professionals to reduce the athletes' risk of injury and/or work on the rehabilitation of these (Hrysomallis, 2011).

Finally, if physical educators, coaches and physical trainers use auditory feedback in postural tasks, they should use 100% or 67% rate. Future studies should check if a lower rate of auditory feedback (*i.e.*, 33%) is as efficient as more frequent feedback for learning a continuous postural control task.

5 Conclusions

In conclusion, practice with both 100% and reduced concurrent auditory knowledge of results feedback obtained changes in postural strategies, reducing the rate of postural corrections during the task. Therefore, 100% or 67% auditory feedback is recommended rather than not providing any auditory feedback in postural control learning.

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Conflict of interest

The authors declare that they have no conflict of interest.

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Ethical approval

The Institutional Review Board of the University of Valencia approved this study.

Author's statement

All authors contributed equally to the work.

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