The effects of unimanual and bimanual massed practice on upper limb function in adults with cervical spinal cord injury: a systematic review

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Funding source: Health Education England Clinical Academic Training Programme Internship Award 2015/2016 (cohort 2).

Conflict of interest: The authors declare no conflict of interest.

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Purpose: To determine whether unimanual massed practice (UMP) and bimanual massed practice (BMP) improve upper limb function in adults with cervical spinal cord injury (cSCI), and the comparative effectiveness of these rehabilitation approaches.

Methods: A systematic search of 5 electronic databases, OpenGrey and relevant reference lists was performed to identify studies investigating the effects of UMP and/or BMP on upper limb function in adults with cSCI. Studies were appraised using a modified version of the Cochrane risk of bias tool. The findings were qualitatively synthesised.

Results: Five randomised controlled trials and 2 case studies were included. Six studies included UMP, 3 included BMP, and 2 compared these approaches. Only 1 study, in which participants received UMP or BMP + somatosensory stimulation, presented a low risk of bias for a functional upper limb outcome. Upper limb function improved significantly in both groups, with no significant between group differences; however the study was limited by its small sample size and lacking a control group.

Conclusions: Preliminary evidence suggests both UMP and BMP may help improve upper limb function post-cSCI, particularly when combined with somatosensory stimulation. However, there is a paucity of high quality studies in this area and further research is warranted.

Keywords: systematic review; unimanual; bimanual; massed practice; cervical spinal cord injury; upper limb function

Word count: 4733

Introduction

Almost 60% spinal cord injuries are at the cervical level [1], resulting in a catastrophic loss of arm and hand function, reducing societal participation and overall quality of life [2]. Given this, it is not surprising that individuals with cervical spinal cord injury (cSCI) cite recovery of arm and hand function as their most important goal during neurorehabilitation [3]. Although a wide range of rehabilitation approaches may improve upper limb function post-cSCI, those currently used in clinical practice are thought to be poorly evidence-based [4]. This is partly due to the dearth of high quality studies in this area and partly because many of the studies conducted have focused on expensive technology which is rarely used in clinical practice [4]. Comprehensive reviews of promising rehabilitation approaches for improving upper limb function post-cSCI, which do not require costly technology, are therefore warranted to help inform clinical practice and highlight areas for future research.

Unimanual massed practice (UMP) and bimanual massed practice (BMP) are 2 such rehabilitation approaches which have shown promise in primary studies, and deserve particular attention due to their recognised benefits in other neurological conditions such as stroke and cerebral palsy [5-7]. Both these interventions involve intense repetitive practice of task-orientated motor activities, using either 1 upper limb (UMP) or both upper limbs (BMP) [8].

UMP may consist of intensive training of 1 limb in isolation or may be a component of a more extensive training intervention such as constraint-induced movement therapy (CIMT), in which intensive training of the more affected limb is combined with restraint of the less affected limb and various behavioural techniques [9]. The intense use of 1 limb and resulting increase in afferent input from that limb is thought to stimulate neuroplastic changes, such as cortical reorganisation, and help minimise “learned non-use”, a phenomenon in which lack of use of a limb results in movement suppression [9]. BMP is also believed to stimulate neuroplasticity, but unlike UMP it is based on the principle of interlimb neural coupling and aims to optimise interhemispheric synchronisation and disinhibition [10,11]. BMP allows both upper limbs to be trained simultaneously; hence may be particularly helpful for individuals with cSCI as their impairments are typically bilateral [12]. It has however also been suggested that UMP may be more beneficial than BMP for individuals with cSCI, as focusing on 1 hand only allows a greater intensity of practice [12].

Despite the potential benefits of UMP and BMP, a prospective study of specialist spinal injury centres in 3 different countries suggested that neither of these approaches are commonly used in clinical practice [13]. Just over 50% of the participants in this study were classed as having tetraplegia; however the average time per participant spent practicing arm and hand activities, such as grasping and lifting, was only 17.5, 31.3 and 49.4 minutes per week in the Netherlands, Australia and Norway respectively.

Given the potential of UMP and BMP to support individuals with cSCI to achieve their most significant rehabilitation goal, investigating their effectiveness is of paramount importance. While 2 recently published systematic reviews investigated spinal cord injury rehabilitation approaches, neither provided a detailed analysis of either UMP or BMP [14,15]. In light of this, the objectives of this review are to investigate:

(1) If UMP and BMP, either alone or combined with additional interventions, improve upper limb function in adults with cSCI.

(2) The comparative effectiveness of UMP and BMP in improving upper limb function in adults with cSCI.

Methods

This review has been conducted according to a protocol registered with the Prospero International Prospective Register of Systematic Reviews (registration number: CRD42016037365, http://www.crd.york.ac.uk/PROSPERO/). The reporting of this review has been based on Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [16].

Eligibility criteria

The primary outcome of this review was change in upper limb function between pre-intervention and post-intervention testing. Secondary outcomes were change in muscle strength, sensory function and corticomotor parameters between pre-intervention and post-intervention testing. To be eligible for inclusion in this review studies had to meet the following eligibility criteria:

- Be a published or unpublished completed study reported in English.
- Include adults (aged 16 or over) with cSCI.
- Include UMP[1] and/or BMP[2].
- Report the primary outcome.

No limitations were applied regarding the type of study design, setting, co-interventions, use of a control/comparator group, injury aetiology, stage post-injury, co-morbidities, functional abilities or ASIA classification.

[1] UMP was defined as repetitive practice of task-orientated motor activities involving use of one upper limb only, for a minimum of 2 hours per day, 5 days per week, for 3 weeks [12].

[2] BMP was defined as repetitive practice of task-orientated motor activities involving use of both upper limbs, for a minimum of 2 hours per day, 5 days per week, for 3 weeks [12].

Search strategy

The following electronic databases were searched from their inception until the 14th of April 2016: the Cochrane Central Register of Controlled Trials (CENTRAL) (in The Cochrane Library), PubMed, the Cumulative Index to Nursing and Allied Health Literature (CINAHL) (EBSCO), Web of Science, and the Physiotherapy Evidence Database (PEDro). Where possible the searches were restricted to English language. In addition, the reference lists of all relevant studies and reviews were hand searched, and OpenGrey was searched to assist identification of relevant unpublished literature.

The search strategies for all the electronic resources apart from PEDro included MeSH terms and text words related to the study participants, interventions and outcomes. The search strategy for PEDro was performed using the advanced search option based on the title and abstract, therapy, body part and method. The search strategies used for all the electronic resources are shown in table S1 (supplementary information).

Study selection

Initially all studies identified by the searches were screened for eligibility by a single reviewer (AA) based on the title and abstract alone. To minimise the chance of any relevant articles being omitted the emphasis of this screening stage was on sensitivity rather than specificity. Full text copies of any potentially relevant studies were then obtained and assessed for eligibility by 2 independent reviewers (AA, JA). All disagreements were resolved by discussion; with a third independent reviewer (SA) being available had this been required.

Data collection

Data about each included study's design, participants, interventions, outcomes and results was extracted using a standardised form, based on recommendations provided by the Cochrane Collaboration [17]. Data extraction was performed by 2 independent reviewers (AA, JA). All disagreements were resolved using the process described above for the study selection.

Study appraisal

The risk of bias of each included study was assessed using a modified version of the Cochrane risk of bias tool (RBT) (table S2, supplementary information). The original Cochrane RBT was designed for use in randomised controlled trials [18]; therefore a modified RBT was developed to enable the same tool to be used in studies with different designs. All the modifications were based on suggestions provided by the Agency for Healthcare Research and Quality (AHRQ) [19].

The modified RBT consists of 6 domains of bias, each comprising 1 or more items. All the domains and items included in the Cochrane RBT were included in the modified RBT; however the random sequence generation and allocation concealment items were only assessed for randomised controlled trials. Furthermore 2 additional items were included in the modified RBT- type of study design (selection bias domain) and concurrent intervention/unintended exposure (performance bias domain). Assessments for the blinding of participants and personnel, blinding of outcome assessment and incomplete outcome data items were made for the upper limb functional outcome measures only. For each included study the reviewers were required to rate the risk of bias for each applicable item as high, low or unclear, and justify the judgement with a supporting statement.

Risk of bias summary assessments, specific to the upper limb functional outcome measures, were made using the approach suggested by the Cochrane Collaboration (table S3, supplementary information) [17]. Due to the inclusion of randomised and non-randomised studies, and the subjective nature of some upper limb functional outcome measures, selection bias; based on the type of study design, and detection bias based on the blinding of outcome assessment, were considered the key domains for the summary assessments. All aspects of the risk of bias assessments were performed by 3 independent reviewers (AA, JA, SA), with disagreements being resolved by discussion.

Study synthesis

The study findings were qualitatively synthesised by considering the following 3 groups: UMP, BMP and UMP versus BMP. In addition the type of design, interventions, comparators and functional upper limb outcome measures of the included studies were compared to determine if a meta-analysis was appropriate.

Results

Study selection

The electronic database and hand searching identified a total of 159 records, 44 of which were duplicates. Screening of the remaining 115 records resulted in 22 records being identified as potentially eligible for inclusion. Three of these records were conference presentations with similar titles to published articles by the same authors and were therefore excluded. Full text eligibility assessments of the remaining 19 articles resulted in 7 studies being identified as eligible for inclusion. Full details of the study selection process and the number of records identified from each electronic database are shown figure 1 and table S1 (supplementary information) respectively.

Study characteristics

Five of the studies were randomised controlled trials (RCTs) [12,20-23] and 2 were case studies [24,25]. The total number of participants across all studies was 93. UMP was included in 6 studies [12,20-24] and BMP was included in 3 studies [12,22,25]. Summaries of the participant characteristics, intervention characteristics and results of the included studies are provided in tables 1, 2, and 3 respectively.

[Tables 1, 2 and 3 near here].

Study synthesis

Two of the included studies were pilot studies [12,21] on which 2 of the other studies were based [20,22]. In addition, none of the studies involved the same design, interventions (including co-interventions and upper limb chosen for UMP/electrical stimulation), comparators and functional upper limb outcome measures; therefore the findings of the included studies were synthesised using a purely qualitative approach.

Study results

UMP

UMP was included in 1 case study [24] and 5 RCTs [12,20-23]. The case study participant received UMP + bimanual task training, and demonstrated an improvement in both BBT and MFT scores [24]. One RCT included intervention groups that received either UMP + somatosensory stimulation (SS) or functional electrical stimulation (FES) and BMP + SS or FES [22]. Although this study did not report the significance of within group changes in outcomes it did report a significant improvement in JTT, but not CAHAI, scores across all participants. The remaining 4 RCTs all included an intervention group that received UMP + SS [12,20,21,23]. All 3 of these studies investigated the significance of pre- to post-intervention changes, and noted that that the UMP + SS group showed significant improvements in all the functional upper limb outcomes assessed [12,21,23].

Three RCTs also included an intervention group that received UMP without concurrent delivery of SS or FES- this group showed significant improvements in both JTT and WMFT scores in 1 study [23] and a significant improvement in JTT but not WMFT scores in 1 study [21]. Of the 3 studies which included both a UMP + SS group and a UMP only group, 1 study reported no significant differences in the improvements in JTT and WMFT scores between these 2 groups [23], while the other 2 studies reported that the UMP + SS group showed significantly greater improvements in these outcomes than the UMP only group [21].

The changes in additional clinical outcomes varied between studies. Two studies reported that the UMP + SS group showed significantly greater improvements in maximal pinch grip strength (MPGS) than the UMP only group [21,23]; however 1 study found no significant difference in the change in MPGS between these 2 groups [20]. Two studies compared sensory outcomes in UMP + SS and UMP only groups, with neither finding any significant differences in the change in sensory outcomes between these 2 groups [20,23]. Two studies did however report significant post-intervention improvements in sensory outcomes in the UMP + SS group [12,23], and 1 study reported that the UMP + SS group showed a significantly greater improvement in sensory outcomes than the control group [21]. Although 1 study reported that the thenar muscle motor threshold decreased significantly in both the UMP + SS and UMP only groups compared to the control group [20], another study reported no significant changes in the motor threshold for the UMP + SS and UMP only groups [21].

BMP

BMP was included in 1 case study [25] and 2 RCTs [12,22]. The case study participant received BMP + SS and demonstrated an improvement in CAHAI and right, but not left, JTT scores [25]. In addition the case study participant's biceps brachii corticomotor map area and normalised map volume increased, and the map centre of gravity shifted anteriorly and medially; however the motor threshold was unchanged. One of the RCTs reported that the BMP + SS group showed significant post-intervention improvements in JTT, CAHAI and sensory scores [12]. The remaining RCT did not report within group changes in outcomes (see preceding section for the post-intervention changes across all participants) [22].

UMP versus BMP

The effects of UMP and BMP were compared in 2 RCTs, 1 combining the UMP and BMP with SS [12], and the other combining the UMP and BMP with SS or FES [22]. Both studies reported significant post-intervention improvements in the JTT scores, either within each group [12], or across all participants [22]. In contrast, only 1 study reported significant post-intervention improvements in the CAHAI scores for the UMP + SS and BMP + SS groups [12], with the other study reporting no significant change in the CAHAI scores across all participants [22].

The latter study did however report that the BMP + SS/FES group showed significantly greater improvements in CAHAI scores than the UMP + SS/FES group

[22], although the other study did not support this finding [12]. Both studies reported that the change in JTT did not vary significantly between the UMP + SS/(FES) and BMP + SS/(FES) groups. One of the studies did however report that its sample size was below that required to detect between group differences in the JTT, and trends in its data suggested that the UMP + SS group made greater progress with the JTT tasks than BMP + SS group [12].

Both RCTs assessed MPGS and sensory sensitivity via the Semmes Weinstein Monofilament Test (SWMT). The only significant post-intervention change identified for these outcomes was an improvement in SWMT scores in both the UMP + SS and BMP + SS groups in 1 study [12], and neither study identified any significant between group differences for these outcomes [12,22]. Both RCTs also assessed thenar muscle corticomotor outcomes, with 1 study reporting a significant post-intervention increase in corticomotor map area across all participants [22]. Furthermore, the other study reported that the post-intervention increase in corticomotor map area across all participants bordered on significance [12]. Neither study investigated between group differences in the corticomotor outcomes due to insufficient numbers of participants completing the corticomotor testing.

Study appraisal

The risk of bias judgements for all the included studies are displayed in table 4, with justifications for the judgements being provided in table S4 (supplementary information).

[Table 4 near here].

The overall risk of bias within 2 of the included studies was high for all the functional upper limb outcomes reported, as these studies employed a case study design and therefore presented a particularly high risk of selection bias [24,25]. The overall risk of bias within 3 RCTs for all the functional upper limb outcomes reported [20,21,23], and within 1 RCT for the JTT [22], was unclear, because these studies presented a low risk of bias for both the type of study design and blinding of outcome assessment, but an unclear risk of bias for at least 3 additional items. The overall risk of bias for the CAHAI within 1 RCT was high, because this study presented a high risk of bias for 4 individual items, including blinding of outcome assessment [22]. The overall risk of bias within the remaining RCT for the JTT was low, because this study presented a low risk of bias for the type of study design, blinding of outcome assessment and 4 additional items [12]. This study's overall risk of bias for the CAHAI was however unclear, as it was not stated if the outcome assessors were blinded and the CAHAI involves subjective judgements; hence the risk of outcome assessor blinding for the CAHAI in this study was unclear.

Discussion

This review aimed to investigate the effects of UMP and BMP on upper limb function in adults with cSCI. Despite employing broad eligibility criteria only 2 case studies and 5 RCTs were identified for inclusion, and 5 of these studies came from the same research group (table 1) [12,20-22,25]. The overall risk of bias for all the functional upper limb outcomes in 6 of the 7 included studies was either high or unclear [20-25]. The remaining study also presented an unclear risk of bias for the CAHAI; however its overall risk of bias for the JTT was low (table 4) [12]. All participants in this study had cSCI of greater than 1 year duration and received either UMP + SS or BMP + SS. Participants in both groups showed significant post-intervention improvements in the JTT, with no significant differences in the change in JTT scores between groups (table

3). The JTT is recognised as a reliable outcome measure for use in individuals with cSCI [26]. These findings therefore suggest that UMP and BMP, combined with SS, may improve upper limb function in adults with chronic cSCI, and that these interventions may be equally effective at doing so.

Nonetheless, the aforementioned study was a pilot study, and its lack of control group and small sample size pose several limitations [12]. Firstly, given the study lacked a control group and the JTT is influenced by learning [26], it is not known whether the improvements made from baseline reflected true improvements in upper limb function or simply learning effects. Consequently, the UMP + SS and BMP + SS rehabilitation approaches may have both been ineffective at improving upper limb function. Secondly, the author's post hoc power analysis predicted a sample of 12 participants per group would have been required to detect significant between group differences in the JTT scores; however the number of participants in the UMP + SS and BMP + SS groups were only 6 and 7 respectively [12]. The study was therefore underpowered to detect significant between group differences, increasing the likelihood that the failure to find a significant difference in the UMP + SS and BMP + SS groups was a false negative. This is a particularly important consideration given that trends in this study's data suggested that the UMP + SS group improved more than the BMP + SS group in the JTT (table 3). Furthermore, the likelihood that the post-intervention improvements in JTT scores for both intervention groups reflect true positives is reduced due to the low power of this study [27]. Thus, even though a low risk of bias for the JTT provides greater confidence in the validity of the results, the lack of a control group and small sample size may negate any robustness in the results for improvement in upper limb function.

Given the limitations of the pilot study described above [12], the same group of authors performed a follow up study in which participants received UMP + SS/FES or BMP + SS/FES [22]. This study employed a delayed intervention design in order to allow comparison of participants who received an intervention to a control group of participants. The change in JTT scores did not differ significantly between the UMP + SS/FES and BMP + SS/FES groups; however, when collapsed by intervention subtypes, the intervention group showing a significantly greater improvement in JTT scores than the control group (table 3) [22]. Since the JTT involves use of one upper limb only, this suggests that the training interventions were effective at improving unimanual function.

In contrast the scores for the CAHAI, which involves use of both upper limbs and hence provides a measure of bimanual function, did not differ significantly between the intervention and control groups (table 3) [22]. The authors suggested that, because the BMP + SS/FES group showed a significantly greater improvement in CAHAI scores than the UMP + SS/FES group, pooling of the training groups weakened the mean difference used in the comparison with the control group [22]. Tentatively, it could be inferred that, whilst both UMP and BMP, regardless of stimulation type, were effective at improving unimanual function, BMP should be used if the focus is on improving bimanual function. Given, that the majority of tasks of daily living involve the use of both hands to some extent [11], BMP may be the most useful type of massed practice to incorporate into a rehabilitation programme. However, this study did present with a high risk of bias for the CAHAI, involved multiple comparisons and, due to participant attrition, its sample size was below that suggested by the power calculation (table 1). Taken together, the limitations of both the pilot study [12] and subsequent study [22] suggest that robust conclusions about the individual and comparative effects of UMP and BMP on upper limb function cannot be drawn.

Three RCTs investigated UMP delivered alone and combined with SS; however 1 of the studies lacked clarity about whether its methodology truly met the requirements of an RCT, and employed inappropriate statistical analyses for the study design employed [23]. In addition 1 of the RCTs was a pilot study which lacked a control group [21]. A subsequent study performed by the same group of authors included UMP only, SS only, UMP + SS and control groups [20]. Although all 3 intervention groups showed significantly greater improvements in JTT scores than the control group, only the SS and UMP + SS groups showed significantly greater improvements than the control group in the WMFT (table 3). This suggests SS may be superior to UMP when either intervention is delivered in isolation. Furthermore the UMP + SS group showed significantly greater improvements in the JTT and WMFT than both the UMP only and SS only groups, with the combination of UMP + SS also showing the greatest benefit in terms of sensation (SWMT) and strength (MPGS) (table 3). This corresponds with evidence that both sensation and strength are key determinants of upper limb function [28]. However, given that this study had an unclear risk of bias for both the JTT and CAHAI, and had a small sample size, its results should be interpreted with caution.

Although no previous systematic reviews have specifically investigated the effects of UMP and BMP post-cSCI, these interventions have been included in systematic reviews investigating the broader topics of exercise therapy and physiotherapy interventions post-cSCI [14,15,29,30]. The results of the present review are largely consistent with these previous reviews, all of which reported that, although the current evidence suggests that exercise therapy/physiotherapy interventions improve upper limb function in individuals with cSCI, there are only a limited number of studies in this area, mostly with small sample sizes.

Limitations

This review has various limitations. Firstly, only a small number of studies were included and it was not possible to combine the results in a meta-analysis. Although this review employed a broad search strategy, it was limited to English and no experts in the field were contacted to assist study selection; hence potentially relevant studies may have been missed. Furthermore it could be argued that the UMP and BMP definitions used in this review were too restrictive, which may have resulted in the exclusion of relevant studies.

Due to the paucity of research in this area, and the fact that many SCI intervention studies do not include a control group [4], no eligibility limitations were applied regarding the type of study design. This led to the inclusion of case studies, which present a particularly high risk of bias [17]. It also meant that a modified version of the Cochrane RBT which has not been validated was used. Arguably the case studies add little to the results of this review and should have been excluded to allow use of the original RBT; however this was not performed to ensure adherence to the registered protocol. The quality of the RCTs included in this review was also limited, with 4 of the 5 RCTs included presenting a high or unclear risk of bias for all the functional upper limb outcomes assessed [20-23] (table 4), and the study authors were not contacted for clarifications. In addition the small sample sizes noted in this review mean that the power of the studies to detect effects was compromised [27].

The Graded Redefined Assessment of Strength, Sensibility and Prehension (GRASSP) is a recently developed tool specifically designed for assessing upper limb function post-cSCI, and has been shown to have good responsiveness and excellent sensitivity when used for this purpose [31]. However none of the studies included in this review used the GRASSP, instead using generic functional upper limb outcome measures, all of which present significant limitations when used in individuals with cSCI. For example the JTT is not only affected by learning, but also fails to detect changes in intrinsic muscles, allows compensatory trunk and shoulder movements and includes tasks which are not representative of the daily tasks performed by individuals with cSCI [26,32]. Finally all the included studies were limited by a lack of long-term follow-up.

Future research

This review provides preliminary evidence that UMP and/or BMP, combined with SS, may assist the rehabilitation of adults with cSCI; however it also highlights the paucity of high quality studies in this area and need for further research. Future studies should investigate UMP and BMP delivered in isolation, to help determine whether concurrent delivery of SS is critical to their effectiveness. In addition the UMP and BMP protocols employed in most of the included studies were very similar in intensity and content (table 2). There is moderate quality evidence that repetitive task training in individuals with stroke is intensity-dependent, with beneficial effects only occurring at high training intensities [6]. Correspondingly, is possible that the failure of some of the studies included in this review to find significant post-intervention improvements in all the functional upper limb outcomes was related to the use of insufficient training intensities. Investigating the effects of different UMP and BMP training intensities in individuals with cSCI is therefore of paramount importance, both to determine the true effectiveness of these rehabilitation approaches and to assist the development of optimal UMP and BMP protocols.

One of the included case studies did not specify the stage post-injury of its participant [24] and all the other studies only included participants who were at least 6 months post-injury (table 1). The early initiation of SCI-specific rehabilitation is extremely important and a delay in starting rehabilitation may negatively influence functional capability [4,33]; hence research into the effects of UMP and BMP at earlier stages post-cSCI is clearly warranted.

Conclusion

This review highlights the paucity of research investigating the effects of UMP and BMP on upper limb function post-cSCI. Of the 7 included studies only 1 presented a low risk of bias for a functional upper limb outcome measure. This study's findings implied that both UMP and BMP, combined with SS, improve upper limb function in adults with chronic cSCI, and that both interventions are similarly effective at doing so. However the study was limited by a small sample size and lack of a control group; hence its findings should be interpreted with caution. Findings from other included studies, all of which presented a high or unclear risk of bias, suggested that BMP may improve bimanual function more than UMP, and that combining UMP with SS may result in greater benefits than either intervention delivered in isolation. Collectively therefore, the findings of the studies included in this review emphasise the potential value of incorporating UMP and BMP into rehabilitation post-cSCI, particularly when combined with SS, but the considerable limitations of all the included studies mean that robust conclusions cannot be drawn. Further research is therefore warranted to investigate many different aspects of UMP and BMP, such as their influence at earlier stages post-cSCI and optimal training protocols.

Acknowledgements

The authors would like to thank the Leeds Teaching Hospitals NHS Trust Physiotherapy Department and Health Education England for enabling the review to be undertaken as part of a Health Education England Clinical Academic Training Programme Internship Award 2015/2016 (cohort 2).

Declaration of interest

The authors report no conflicts of interest.

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