# Qualitative and quantitative assessment of magnetic vestibular stimulation in humans

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## Abstract

The sensation of phantom motion or exhibition of bodily sway is often reported in the proximity of an MR scanner. It is proposed that the magnetic field stimulates the vestibular system. There are a number of possible mechanisms responsible, and the relative contributions of susceptibility on the otolithic receptors and the Lorentz force on the cupulae have not yet been explored. This exploratory study aims to investigate the impact of being in the proximity of a 7.0 T MR scanner.

The modified clinical test of sensory interaction on balance (mCTSIB) was used to qualitatively ascertain whether or not healthy control subjects who passed the mCTSIB in normal conditions 1) experienced subjective sensations of dizziness, vertigo or of leaning or shifting in gravity when in the magnetic field and 2) exhibited visibly increased bodily sway whilst in the magnetic field compared to outside the magnetic field. Condition IV of the mCTSIB was video recorded outside and inside the magnetic field, providing a semi-quantitative measure of sway.

For condition IV of the mCTSIB (visual and proprioceptive cues compromised), all seven locations/orientations around the scanner yielded significantly more sway than at baseline ($p < 0.01$ FDR). A Student's t-test comparing the RMS velocity of a motion marker on the upper arm during mCTSIB condition IV showed a significant increase in the amount of motion exhibited in the field (T=2.59; d.f.=9; p=0.029) compared to outside the field.

This initial study using qualitative measures of sway demonstrates that there is evidence for MR-naïve individuals exhibiting greater sway while performing the mCTSIB in the magnetic field compared to outside the field. Directional polarity of sway was not significant. Future studies of vestibular stimulation by magnetic fields would benefit from the development of a sensitive, objective measure of balance function, which can be performed inside a magnetic field.

**Keywords:** vestibular, magnetic resonance imaging

## Introduction

The human balance system utilises the integrated input from a number of different sensory systems (vestibular, visual and proprioceptive) to provide both postural stability of the body and image stability of the visual world. The relative dominance of each of these sensory inputs is situation/task dependant and is usually controlled subconsciously, although conscious control can be adopted. The vestibular end organ, located within each inner ear, comprises a system sensitive to rotational motion in various planes (the semi-circular canals) and one sensitive to linear acceleration and/or the Earth's gravitational field direction (the otoliths). Magnetic resonance (MR) scanners use extremely strong magnetic fields to create bulk magnetisation in the form of alignment of the nuclear magnetic dipoles in the body. Many people report the sensation of phantom motion when in the close proximity of an MR scanner [10]. The mechanism behind this perception is not fully understood [11]. Previous research has identified that people working in and around high-strength magnetic fields (for example, those operating the machines) report a sensation of dizziness [10]. Anecdotally, operators standing at the end of the bore of the 7.0 T magnet can appear to sway when visual fixation is removed; for example upon closing their eyes. This effect is amplified by reducing

67  the accuracy or efficacy of proprioceptive **or somatosensory cues, when vestibular cues would**

68  **become the dominant sense used for postural stability. As such, whilst it is accepted that sway is a**

69  **multisensory phenomenon,** it is proposed that the magnetic field stimulates or modifies the

70  function of an individual's vestibular system. Considering the physics of magnetic field interactions

71  with biological systems, it is possible to postulate four mechanisms for the transduction of magnetic

72  fields in the vestibular system: forces due to the magnetic susceptibility of vestibular structures [3];

73  current flow due to a net rate of change of magnetic flux [3]; magneto-hydrodynamic (MHD) effects

74  due to rapid head movement [3, 8] and fluid pressure due to Lorentz forces originating from the

75  interaction between hair cell currents and the magnetic field [7]. Differentiation between these

76  possible mechanisms is not straightforward. In the present experiment we sought to examine only

77  those mechanisms with no temporal rate-of-change of field: as the subject in the present

78  experiment is nominally static (or has negligible velocity), any effects due to induced currents and

79  MHD can be largely ignored [3]. However, there remains a degree of ambiguity in the understanding

80  and interplay between the two significant remaining biophysical mechanisms of susceptibility and

81  Lorentz forces. As the semi-circular canals detect rotational motion in the plane of the canal(s)

82  stimulated and hence initiate a vestibular ocular reflex in the same plane in an attempt to stabilise

83  the visual world during rotation, any erroneous asymmetric stimulation of these would most likely

84  produce a subjective sensation of rotation/vertigo in the plane of the canals involved, centred in the

85  head. Conversely the otoliths signal linear acceleration or gravitational direction, therefore

86  erroneous stimulation of those would likely produce a shift in the vertical axis of the body (static

87  lean) and/or head, and possibly a skew deviation of the eyes which would produce a perceptual shift

88  of visual vertical/horizontal (these effects also happen in the acute stages of unilateral otolithic

89  damage). Some of these mechanisms have been investigated [5, 6], however, the mechanism of

90  susceptibility on the otolithic membranes has not yet been explored. The vestibular receptors of the

91  otoliths are used by the brain to signal linear acceleration and orientation with respect to gravity by

92  use of movement of a weighted overlying substrate. Any interaction of the magnetic field with the

93  vestibular receptors of the cupula might also stimulate the otolithic receptors in a similar way and, if

94  so, this might potentially alter gravitational reference and/or induce sensations of linear acceleration

95  alongside any sense of rotation.

96  Future advancement in the understanding of vestibular physiology may be associated with potential

97  clinical applications, as it may represent a novel method of vestibular stimulation [11]. Existing

98  techniques cannot provide sustained stimulation of the sensory receptors due to hydrodynamic

99  fatigue (i.e. any physical rotation or thermal stimulation has the effect that the relative difference in

100    motion between the wall of the semi-circular canal, and hence cupula, and the fluid within reduces

101    on prolonged rotation due to inertia effects or due to temperature equalisation).

102    The modified Clinical Test of Sensory Interaction on Balance (mCTSIB) is an example of a clinical

103    balance test for the identification of vestibular impairment [1, 4, 9]. Participants are observed during

104    upright stance, and their degree of natural postural sway subjectively assessed, under various

105    conditions designed to aid sensory isolation. Hence, assessment is made with and without visual

106    cues (eyes open and closed) and in the presence of effective and compromised proprioceptive

107    **and/or somatosensory** cues (standing on a firm support surface or on foam). Each condition

108    increases in complexity, such that individuals with no-known vestibular deficit may experience sway

109    across any of the conditions but should be able to maintain their stable stance as the brain

110    effectively uses the most accurate sensory cues available to it in any given situation. In contrast,

111    individuals with known vestibular deficit will typically perform well when appropriate visual and/or

112    proprioceptive cues are available, but their performance will deteriorate more markedly as these

113    cues are removed/compromised and the vestibular cues becomes more important. Evidence of

114    impaired mCTSIB performance has been consistently shown in those with vestibular deficit [2],

115    particularly in Condition IV. Identification of failure to maintain balance during the mCTSIB signifies a

116    high likelihood of vestibular pathology.

117    This research investigated the potential mechanism behind the phantom sensation of motion when

118    in the proximity of a magnetic field produced by a 7.0 T MR scanner, in semi-isolation from the other

119    components of balance; visual and proprioceptive cues, using the mCTSIB.

120    The objectives of this study, were to qualitatively ascertain:

121        1.    Whether individuals with self-reported normal balance experience any subjective

122              sensations of dizziness, imbalance or sensation of leaning or shifting in gravity when

123              in the magnetic field

124        2.    Whether or not these individuals exhibit a static off-vertical-axis lean or

125              demonstrably increased bodily sway whilst in the magnetic field vicinity of the MR

126              scanner compared to outside the magnetic field, suggestive of shifted perception of

127              gravity

128        3.    Whether degree and direction of response is reliably and repeatably dependent on

129              direction of magnetic field lines experienced, which potentially would inform the

130              likely dominant underlying mechanism.

131    Subjective sensations of vertigo/dizziness are typically associated with a relative imbalance between

132    the semi-circular canal inputs from each ear's vestibular end organ (responsible for the detection of

133    angular acceleration and the subsequent generation of a compensatory vestibular ocular reflex).

134  Otolithic dysfunction may be associated with an inappropriate shift in the body's vertical alignment,

135  a skew deviation of the eyes and a change in the perceived horizontal/vertical visual reference. All

136  symptoms however vary with time as the brain adjusts to compensate for any perceived sensory

137  conflict.

138  The effects of any inappropriate/unexpected change in vestibular signals (if not acute/severe) can be

139  masked by proprioceptive and visual cues, since these are more dominant in everyday life. It is

140  therefore more likely to see any effects of vestibular stimulation by magnetic field when a person

141  has these visual and proprioceptive cues removed or compromised (i.e. standing with eyes closed on

142  foam). Increased static lean or tilt while standing on foam with eyes closed would be suggestive of

143  an otolithic effect. If this were observed, or participants were to report a sensation of static leaning

144  or tilting when in the magnetic field, that would be again more consistent with otolithic than with

145  semi-circular canal stimulation.

146  We hypothesised that individuals with self-reported normal vestibular function who passed the

147  baseline mCTSIB and were naïve to the magnetic field may exhibit an increased degree of lean or

148  sway and/or report increased sensations of vestibular stimulation.

149

150  **Materials and Methods**

151  **Participants**

152  Experimental procedures conformed to the World Medical Association's Declaration of Helsinki and

153  were approved by the University of Nottingham Faculty of Medicine and Health Sciences Research

154  Ethics Committee (reference: 421-1911). All participants gave written informed consent prior to

155  participating in the study.

156  Ten healthy individuals (7 female; 3 male) were recruited into the study by advertisement. Criteria

157  for inclusion were self-reported normal hearing, vision (or corrected-to-normal using contact lenses)

158  and balance, no history of balance problems and no contraindications for MR. Participants were also

159  not familiar with moving through the magnetic field of an MR scanner, and had never been in the

160  proximity of a 7.0 T MR scanner. Participants were aged between 24 and 56 years, and the mean (±

161  st.dev.) age was 35 (± 11). Participant heights were between 158 and 180 cm tall, with mean 167 (±

162  8) cm (individual participant heights are given in Table 1).

163  **mCTSIB**

164  The mCTSIB was used to isolate each component of balance, one at a time. The individual was asked

165  to stand upright and as still as they were able for 30 seconds in each of a series of test conditions.

166  The test is designed such that each successive condition reduces sensory input, in order to help to

determine whether or not vestibular balance cues are being used appropriately. The mCTSIB conditions are:

I.    standing on firm floor, with eyes open (subject has potential access to appropriate visual, proprioceptive and vestibular cues)

II.   standing on firm floor with eyes closed (visual cues are removed whilst proprioceptive and vestibular cues remain appropriate)

III.  standing on a foam cushion, eyes open (proprioceptive cues are compromised whilst visual and vestibular cues remain appropriate) and

IV.   standing on foam cushion with eyes closed (visual cues are removed, and proprioceptive cues are compromised leaving only vestibular cues appropriate)

In healthy individuals with normal visual, proprioceptive and vestibular inputs, postural stability should be possible under all four conditions of the mCTSIB, with no falls and minimal bodily sway. Individuals with a vestibular pathology are likely to fail/perform poorly under condition IV, since their vestibular input is inappropriate and their remaining sensory cues are removed or compromised. Prematurely opening the eyes and/or taking a step would also be considered to cause a fail of any condition.

***Scoring and analyses***: Performance on the mCTSIB was scored qualitatively by a qualified Clinical Scientist (Audiology) experienced in assessing patients in vestibular audiology clinics in the UK. For each condition (I through IV) of the mCTSIB, and each location/orientation within the magnetic field, the participant was allocated a score for the degree of sway exhibited such that 0 was corresponded to exhibiting minimal sway and 4 corresponded to a large degree of sway. Scores of 0, 1 or 2 would be considered a pass on the mCTSIB when used in a clinical setting. Intra-subject differences were assessed using **non-parametric statistical analyses in the form of Wilcoxon Signed Ranks tests performed in IBM SPSS (version 25, IBM, Armonk, NY, USA).**

**Procedure overview**

Functional vestibular performance was first assessed using the mCTSIB in the neutral environment outside the magnetic field of the MR scanner.

Subsequently, individuals were asked to perform the mCTSIB inside the magnetic field produced by a Philips 7.0 T Achieva MR scanner (Philips Healthcare, Best, Netherlands). The mCTSIB was performed at a set of positions (each defined as a location and orientation) around the magnet, chosen for their symmetry or anti-symmetry relative to the magnetic field and head (see Figure 1). For example, three locations, spanning both ends ('north' and 'south') of the magnet and both sides of the bore were chosen such that the magnetic field profile across the head is identical, yet the polarity of the field is reversed. The susceptibility mechanism would be expected to yield identical subject

201  response, whereas a dominant Lorentz Force mechanism would potentially reverse the effect. The

202  subject additionally repeated the mCTSIB at different orientations in each location, for example

203  parallel to the MR scanner bore and at 90° to the bore, in order to investigate the effect of

204  orientation of head orientation on the measurement.

205  A qualitative estimation of the magnitude, latency and direction of participant sway, alongside

206  recording any subjective perception occurred at each location and orientation. Figure 1 shows the

207  7.0 T magnet hall and three locations for subjects in the magnet hall. Location B is magnetic field

208  polarity reversed relative to location A. Location C is head/vestibular organ symmetric to location A.

209  In summary, the mCTSIB was performed in the locations given in Table 2. Magnetic field strengths

210  (modulus B or |B|) and the field-gradient product strengths (modulus of gradient of B times B or

211  |GB|) experienced at the location of the participant's head, together with participant heights are

212  given in Table 2. The mean time spent in the magnet hall (i.e. total duration of in-field testing) was

213  22 (± 7) minutes (range 17 to 40 minutes).

214  **Video recordings of sway**

215  Video recordings were acquired using a Canon EOS 1100D Digital SLR Camera (Canon Incorporated,

216  Ota City, Tokyo, Japan). Images were acquired at a resolution of 1280 × 720 pixels and frame rate of

217  29.97 frames per second. Each participant was recorded for mCTSIB condition IV in the first two

218  trials (i.e. outside the magnetic field and location A, facing West). For both recordings, the camera

219  was placed such that there was a distance of 509 cm from the edge of the foam to the nearest foot

220  of the tripod. Approximately 30 s recording took place for each of these two trials.

221  During recording, the participant wore a sticker on their upper arm for motion tracking. A frame of

222  one such video is provided in Figure 2.

223  *Processing and analysis:* Videos were processed using in-house software written in Matlab (version

224  2018a, The MathWorks Inc., Natick, Massachusetts) to extract motion of the cross on the

225  participant's arm as a proxy for sway. Absolute in-plane displacement of the cross from its position

226  in frame 1 was computed for each frame of each recording. Mean and standard deviation

227  displacement across the first 25-second period of this recording was also computed. Intra-subject

228  differences were assessed using **a Mann-Whitney U-test.**

**Measurement of the local magnetic field**

Measurements of the local magnetic field vector, **B**, and full gradient tensor, G, were made by constructing a small array of 12 Hall-effect sensors (HE144P Asensor Technology AB, Bålsta, Sweden) mounted on a 40-mm cubic block in order to measure the field components required.

Measurements were made at locations A and C by placing the magnetic field sensor in the space occupied by the participant's head just as they stepped off the foam following performing the mCTSIB. Measurements were not made at location B due to the length of the device cable available but can be inferred by symmetry. Mean and standard deviation values for the modulus of B (|B|) and the modulus of the gradient-field product (|GB|) are given in Table 2.

## Results

**mCTSIB**

All (n = 10) participants passed conditions I through IV of the mCTSIB when performed outside the magnetic field both before and after magnetic field exposure. All participants passed condition I of the mCTSIB in all magnetic field test condition (MFT) positions (i.e. locations A-C in all orientations). One participant was assigned two 'non-zero' scores when performing condition II; in one position this was a score of 2 (still a pass) and the other position a 3 (a fail). **Wilcoxon Signed Rank** tests showed these differences in condition II scores were not significant across the group (**p = 0.32** in both positions). A different participant was assigned a score of 2 (pass) when performing condition III in one position, which was also not significant across the group (**p = 0.32**).

For condition IV of the mCTSIB (vestibular cue dominant), all seven MFT positions yielded significantly more sway than at baseline, at a threshold of **p < 0.05 using Wilcoxon Signed Rank tests. The significance for each of these comparisons is given in the third column of Table 2.** This amounted to six participants being assigned a score of 4 in at least one MFT position (9 positions total scoring 4) and six participants being assigned a score of 3 in at least one MFT position (13 positions total scoring 2). Cumulatively, 7 participants failed a total of 22 conditions. Notably, five out of the ten participants failed both condition IV tests in both orientations of location B (behind the scanner – see Discussion). Four out of the ten participants failed the first position in the magnetic field (location A facing West – see Discussion).

**Video recordings of sway**

Figure 3 shows plots of displacement of the visual marker on the arm of the participant during mCTSIB condition IV. Black lines refer to the recording made of the trial outside the magnet hall (Table 2, line 1) and grey lines represent the recording made of the first trial inside the 7.0 T magnet

hall (location A, facing West). Dashed and dotted lines represent individual sway recordings outside and inside the magnet hall respectively, whereas solid lines represent the group mean.

The mean displacement over time, and across the group was 1.20 (± 0.82) cm outside the field and 1.40 (± 0.86) cm inside the field. The standard deviation of displacement of the marker over time was 0.59 (± 0.31) cm outside the field and 0.87 (± 0.45) cm inside. The difference between inside and outside the field was non-significant for the mean displacement (p = 0.5) but was significantly higher for the standard deviation of displacement inside the field compared to outside the field (T = 2.41; d.f. = 9; p = 0.04).

A **Mann-Whitney U-test test** between the group mean displacement outside the scanner (i.e. the solid black line on Figure 3) and the group mean displacement outside the magnet hall (i.e. the solid grey line on Figure 3) showed a significantly higher displacement overall occurring in the recording made inside the magnet hall (**p < 0.001**).

**Dependence of balance performance on field strength and direction**

ANOVA statistics showed that there was no significant effect of field direction on the mCTSIB condition IV score. Where there was a demonstrable direction to a participant's lean or sway during mCTSIB condition IV, this was usually in the forward/back direction. This amounted to 9 occurrences of backward lean/sway, 17 occurrence of forward sway and 16 occurrences of forward/back lean/sway, compared to one occurrence left, one occurrence right and two occurrences left/right out of 46 mCTSIB condition IV trials when lean/sway had a perceptible direction. The remaining 24 mCTSIB condition IV trials did not exhibit lean/sway with a perceptible direction. These data are not clear enough to draw any conclusions from.

There was no correlation between the modulus of the magnetic field (|B|) or the modulus of the gradient-field product (|GB|) and the participant's score on the mCTSIB condition IV (2-tailed **Spearman's Rank** Correlation, p > 0.1 for all locations and directions where local magnetic field measurements were made.

**Subjective reports of perception**

Participants were asked to comment on any sensations experienced after each completed mCTSIB condition IV trial. Seven out of the ten participants reported "feeling unsteady, "rocking", "swaying", "pulling" or "being pulled", "pushing" or "being pushed" in directions described as "side to side", "forwards" or "backwards". Some participants reported sensations of "linear acceleration" or "rotating in a horizontal plane", whereas others described it as the need "to use knees more", "lock knees", to "correct posture" or "correct posture by leaning". Additionally, one participant reported feeling "tingly fingers on entering the field".

295 Based on the limited number of instances where participants could confidently report which

296 direction they perceived the motion/offset to be in, few conclusions can be drawn from the data.

297 The directions of participant-reported perceived motion are given in Figure 4, for each MFT position

298 (location and orientation) within the field.

299

## Discussion

### Study findings

302 We report a novel investigation into the effect of a magnetic field of order 1 T with gradient-field

303 products of up to 3 $T^2m^{-1}$ on balance performance in ten healthy adult volunteers with self-reported

304 normal balance function. Across the group, participants performed significantly poorer on condition

305 IV of the mCTSIB (vestibular cue dominant with vision removed and proprioception compromised)

306 and exhibited significantly more motion or sway in video recordings of mCTSIB condition IV relative

307 to their baseline condition. We interpret this as the subject working harder to maintain balance

308 when in the magnetic field as compared to baseline.

309 Four out of the ten participants failed the first position in the magnetic field (location A facing West).

310 As this was the first position where the mCTSIB was performed inside the magnetic field, and

311 subsequent repeats of the mCTSIB at the same location (albeit different orientations) were failed

312 less often, it may be that participants exhibited some adaptation to the control of their naturally

313 occurring postural sway within the magnetic field. This may reflect a behavioural adaptation or

314 possibly an increased tolerance or familiarity with the sensation of being within the field, which

315 allowed them to maintain balance more easily over time.

316 This research set out to assess the frequency with which participants failed the later conditions (II, III

317 and IV) of the mCTSIB in the proximity of a 7.0 T MR scanner. However, in individuals with no self-

318 reported balance disorder, the degree of sway was very similar between conditions as measured

319 using the mCTSIB. As such, some attempt was made to use this qualitative measure to differentiate

320 the degree of sway exhibited, but this research shows that the mCTSIB does not provide a reliable

321 enough differentiator of degree of sway. Therefore, we cannot report for certain whether the

322 experimental design in the current study was insensitive to the effect we were attempting to

323 measure, or conversely that there was no effect present to measure.

324 Participants were not moving with any great velocity while conducting the tests, and any motion

325 exhibited resulting from bodily sway was slow. Therefore, any effects due to induced currents and

326 MHD can be ruled out. As such, only mechanisms with no temporal rate-of-change of field are being

327 considered.

328    If it were the case that the static magnetic field influenced the otolithic receptor, then we might

329    expect the participant to exhibit a perceived shift in their gravitational reference axis, which would

330    lead to a 'tilt' or 'off-vertical-axis' stance, and/or potentially a skew deviation of their eyes, rather

331    than an increase in dynamic sway magnitude or a sense of rotation / vertigo.

332    **While the measures used in this study only account for a clear degree of sway exhibited while in**

333    **the magnetic field compared to outside the field, we also observed many/most participants adopt**

334    **a different postural strategy when tested in the magnetic field compared to that outside the field**

335    **(i.e. they tended to tense or lock their knees upon closing their eyes while in the magnetic field i.e.**

336    **the transition from mCTISB condition I to II or III to IV). Further, many participants exhibited very**

337    **small amplitude sway, or 'jiggling' as a result of their tense or locked knees or continually**

338    **correcting motion, possibly reflecting a more conscious approach to the maintenance of their**

339    **postural stability compared to a more natural sub conscious response pattern seen when testing**

340    **outside the magnetic field. Additionally there may have been some influence of anticipation of a**

341    **forthcoming vestibular sensation.**

342    **Avenues for future research**

343    The present study did not aim to measure stance or any **metrics of gaze**. The set-up of the foam with

344    eyes closed could additionally be used to observe any off-axis body posture since it would reduce

345    the effectiveness of the proprioceptor cues in assessing 'true horizontal' in addition to removing

346    visual room cues for earth fixed vertical/horizontal. If a participant were to fail this test in the

347    magnetic field, having passed it in normal conditions, this would be indication of magnetic vestibular

348    stimulation.

349    Future research in this area will require the use of quantitative measurements with sensitivity and

350    specificity for objectively identifying the presence off-vertical axis postural positioning and/or a

351    change in natural body sway in the presence of the externally applied magnetic field. Unfortunately,

352    the mCTISB is a qualitative not quantitative measurement technique. Further, whilst analysis of the

353    video recordings of sway do provide a quantitative measure, the implementation of the technique in

354    this study does not provide the required sensitivity to judge whether or not there is an effect to

355    detect.

356    As mentioned previously, the recording method used may not be sensitive enough to detect this

357    small degree of very rapid motion. This may present an opportunity for investigation of

358    electromyography recordings in the legs between the two locations. However such recordings are

359    likely to be plagued by artefacts caused by the magnetic field that one would expect to correlate

360    very highly with motion. Alternative forms of motion marker could be developed in order to increase

361    the sensitivity of the motion video recording measure, while still ensuring that the test can be

362    performed inside a strong magnetic field. For example a mirror attached directly to the knees that

363    would reflect the path of a laser light onto a wall for amplification of the degree of motion thus

364    significantly increasing the sensitivity of the technique to detecting the very small degrees of rapid

365    motion observed and reported anecdotally.

366

## Conclusion

368    This initial study using qualitative measures of sway demonstrates that there is evidence in favour of

369    MR-naïve individuals exhibiting a greater amount of postural sway while performing the mCTSIB in

370    the magnetic field compared to outside the field (baseline). While the mCTSIB does not provide

371    sufficient quantitative evidence for this effect, video recordings provide increased sensitivity. Due to

372    the subtle nature of the effect, we were not able to confidently differentiate between the two

373    biophysical mechanisms of susceptibility and Lorentz forces. As such, higher still sensitivity will be

374    required in future studies to determine which mechanism is responsible for the effect.

375    Understanding these mechanisms further would benefit from the development of an objective and

376    highly sensitive quantitative measure of balance function that can be performed inside a strong

377    magnetic field.

378

## Abbreviations

380    mCTSIB = modified clinical test of sensory interaction on balance; MR = magnetic resonance; MRI =

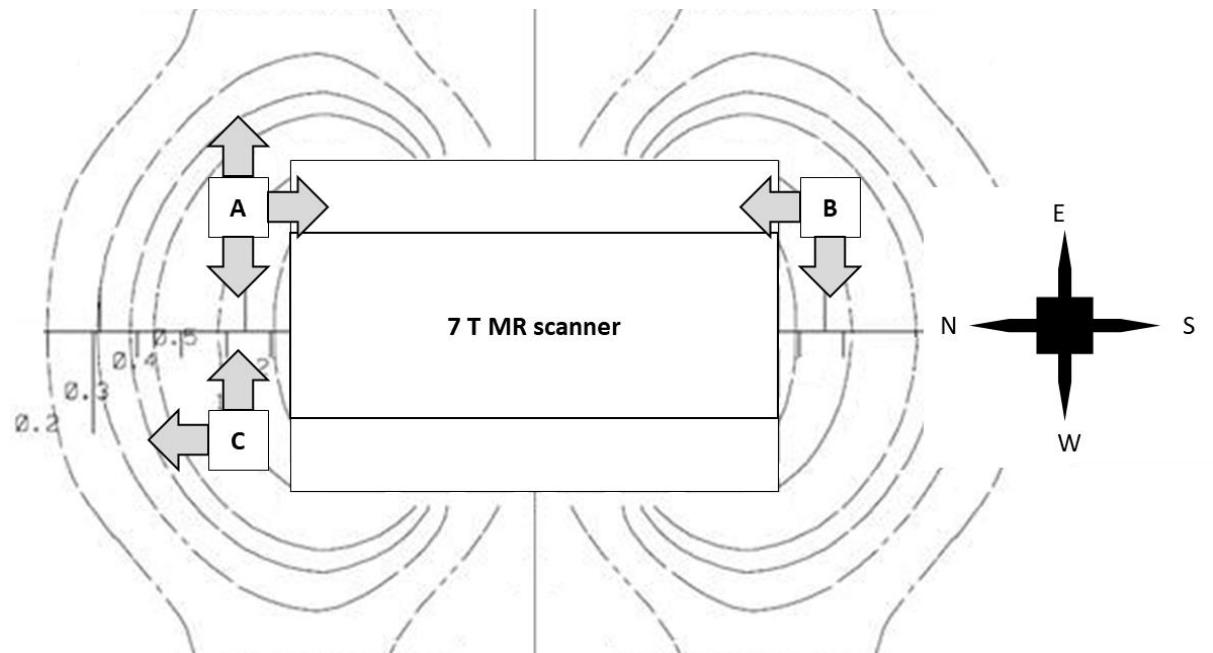381    magnetic resonance imaging; RMS = root mean square;

382

## Figures



384

Figure 1: Schematic of the relative locations of mCTSIB trial positions relative to the 7.0 T MR scanner. **Curved lines represent approximate field lines produced by the scanner, and numerical labels represent the strength of the magnetic field, in tesla.**

388

389

390   Figure 2: Example frame from recording of mCTSIB in MFT location 'A', facing West, showing the

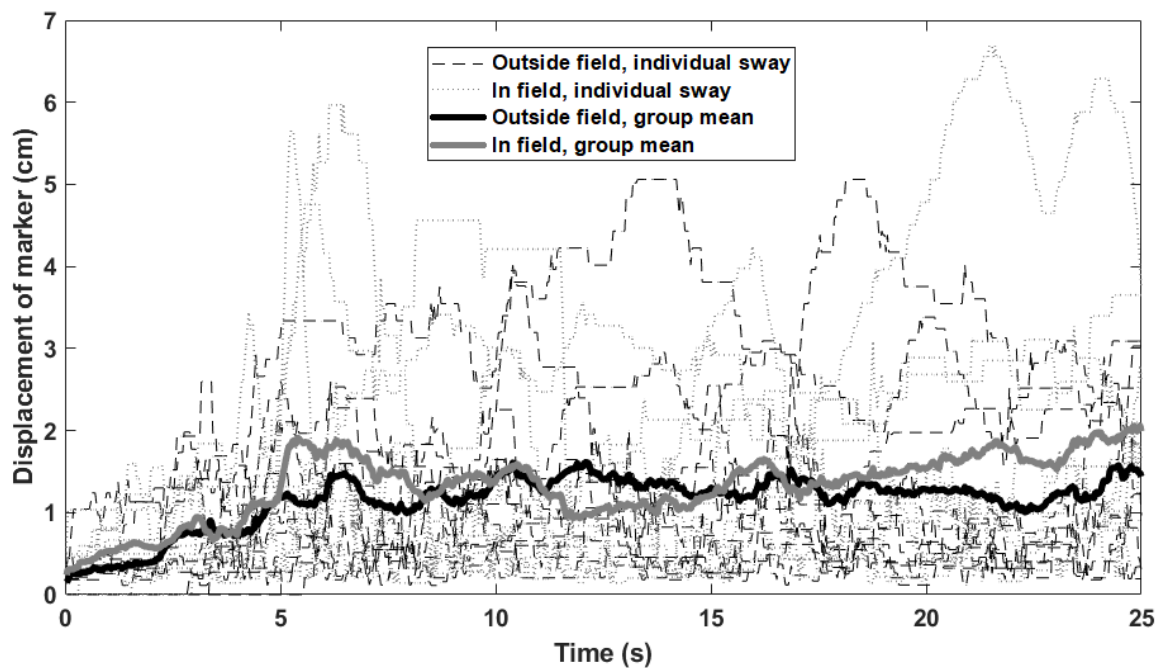391   sticker on the participant's upper arm that was used for motion tracking.

392



393

394   Figure 3: Plots of displacement of the visual marker on the arm of participants during mCTSIB

395   condition IV both outside (black) and inside (grey) the 7.0 T magnet room. Dashed and dotted lines

396    represent individual sway recordings outside and inside the field respectively, whereas solid lines

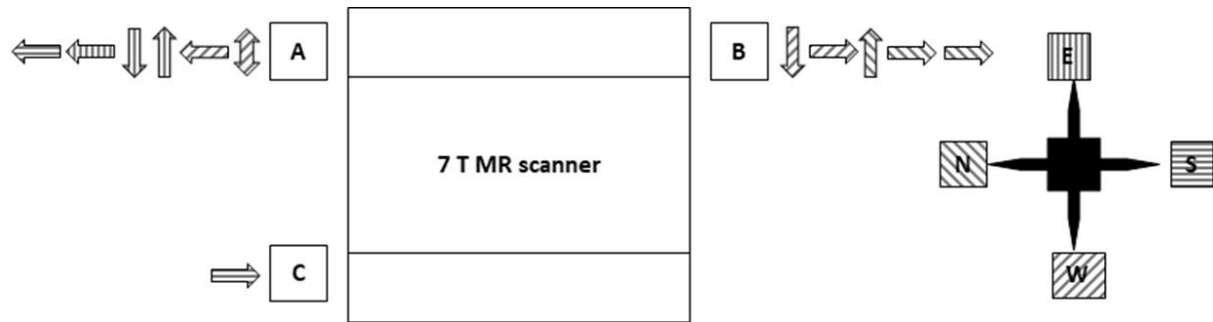397    represent the group mean.

398



399

400    Figure 4: Schematic of the relative directions of participant-reported perceived motion at various

401    trial locations and orientations relative to the 7.0 T MR scanner. Stripe directions within the arrows

402    represent the directions the participant was facing at the time, corresponding to the stripes on the

403    compass points. Directions of arrows correspond to directions of reported perceived motion.

404

405    **Tables**

| Participant height | Mean (± st.dev) \|B\| | Mean (± st.dev) \|GB\| |
|:---:|:---:|:---:|
| 167 cm | 0.82 (± 0.04) T | 2.68 (± 0.42) $T^2m^{-2}$ |
| 166 cm | 0.82 (± 0.05) T | 1.77 (± 0.29) $T^2m^{-2}$ |
| 173 cm | 0.84 (± 0.07) T | 2.11 (± 0.49) $T^2m^{-2}$ |
| 158 cm | 0.82 (± 0.04) T | 2.54 (± 0.12) $T^2m^{-2}$ |
| 158 cm | 0.84 (± 0.03) T | 2.78 (± 0.27) $T^2m^{-2}$ |
| 163 cm | 0.78 (± 0.06) T | 2.46 (± 0.16) $T^2m^{-2}$ |
| 170 cm | 0.80 (± 0.03) T | 2.54 (± 0.39) $T^2m^{-2}$ |
| 180 cm | 0.77 (± 0.02) T | 2.23 (± 0.56) $T^2m^{-2}$ |
| 178 cm | 0.77 (± 0.03) T | 2.22 (± 0.46) $T^2m^{-2}$ |
| 163 cm | 0.82 (± 0.02) T | 2.69 (± 0.50) $T^2m^{-2}$ |

406    Table 1: Mean and standard deviation values for the individual field strengths (modulus B or |B|)

407    and gradient product (modulus GB or |GB|) experienced by participants. Participant heights given

408    for reference.

409

| Location | Orientation | Mean (± st.dev) $\|B\|$ | Mean (± st.dev) $\|GB\|$ | Group difference from baseline |
|---|---|---|---|---|
| Outside field | N/A | N/A | N/A | **n.s.** |
| A | W | 0.82 (± 0.03) T | 2.62 (± 0.42) $T^2m^{-2}$ | **0.017** |
| A | E | 0.79 (± 0.06) T | 2.49 (± 0.38) $T^2m^{-2}$ | **0.026** |
| A | S | 0.78 (± 0.03) T | 2.62 (± 0.42) $T^2m^{-2}$ | **0.041** |
| B | W | Not measured | Not measured | **0.010** |
| B | N | Not measured | Not measured | **0.017** |
| C | E | 0.84 (± 0.04) T | 2.24 (± 0.32) $T^2m^{-2}$ | **0.016** |
| C | N | 0.80 (± 0.05) T | 2.01 (± 0.52) $T^2m^{-2}$ | **0.011** |
| Outside field | N/A | N/A | N/A | **n.s.** |

Table 2: MFT positions (made up of a location and orientation) at which the mCTSIB was performed.

Locations A, B and C and compass point directions refer to those marked on Figure 1. The group

difference from baseline represents the **significance of Wilcoxon Signed Rank tests between**

**condition IV and condition I. 'n.s.' denotes a non-significant difference.**

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