Hindawi Publishing Corporation
BioMed Research International
Volume 2015, Article ID 647510, 8 pages
http://dx.doi.org/10.1155/2015/647510

R A

B

,[1] ,[2] ,[2] . B ,[3]
,[4] B 1,5

D O V S , U A , B , L , P R , G ,
A , N
D P , P U , H R , H , B , C
D S E S , U A , S S , A , N
D M , U A , S S , A , N
S O V S , U W , C S W, W , ON, C N L G

Correspondence should be addressed to Ehsan Vaghe ; e.vaghe @auckland.ac.nz

Received 23 June 2014; Revised 13 August 2014; Accepted 9 September 2014

Academic Editor: Zhengchao Dong

Copyright © 2015 Ehsan Vaghe et al. is is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

A key issue in the eld of noninvasive brain stimulation (NIBS) is the accurate localization of scalp positions that correspond to targeted cortical areas. e current gold standard is to combine structural and functional brain imaging with a commercially available "neuronavigation" system. However, neuronavigation systems are not commonplace outside of specialized research environments. Here we describe a technique that allows for the use of participant-speci c functional and structural MRI data to guide NIBS without a neuronavigation system. Surface mesh representations of the head were generated using Brain Voyager and vectors linking key anatomical landmarks were drawn on the mesh. Our technique was then used to calculate the precise distances on the scalp corresponding to these vectors. ese calculations were veri ed using actual measurements of the head and the technique was used to identify a scalp position corresponding to a brain area localized using functional MRI.

1.

Noninvasive brain stimulation (NIBS) techniques such as repetitive transcranial magnetic stimulation (rTMS) and transcranial direct current stimulation (tDCS) allow for the temporary modulation of neural activity within the human brain. rTMS involves the induction of weak electrical currents within targeted regions of the cortex via brief, time-varying magnetic elds produced with a hand-held coil [1]. tDCS employs head-mounted electrodes, which allow for a weak direct current to interact with the underlying cortex [2]. NIBS can be used to investigate the role of individual brain areas in speci c cognitive, behavioral, or perceptual processes [1]. In addition, these techniques are being investigated from a clinical perspective and current evidence suggests that NIBS may be applicable to the treatment of multiple neurological and psychiatric disorders [3, 4].

Studies involving the use of NIBS begin by selecting a target brain area for stimulation. is process is typically informed by evidence from brain imaging, animal neurophysiology, or studies involving neurological patients. Subsequent steps include the selection of appropriate stimulation parameters and ensuring that the stimulation is delivered to the correct brain area. is latter point is particularly important as the stimulation e ects are most pronounced in close proximity to the rTMS coil and tDCS electrodes [5]. erefore, accurate, participant-speci c localization of stimulation sites on the scalp is required for optimal stimulation [6].

A number of approaches can be used to identify the correct scalp position for stimulation. Single pulse TMS can be used to activate speci c regions of the primary motor cortex resulting in motor evoked potentials (MEPs) within the corresponding peripheral muscle [7]. e scalp location

that evokes the strongest MEP can then be used as the location for rTMS or tDCS. A comparable technique also exists for the visual cortex whereby single pulse TMS of the occipital pole can be used to evoke the percept of a phosphene [8]. e scalp location that induces the most robust phosphene or a phosphene in a speci c visual eld location can be used for visual cortex stimulation. A similar technique can be used for motion sensitive, extra-striate visual area V5 whereby TMS can be used to induce moving phosphenes [9]. It has been shown that this technique is in good agreement with localization of V5 using functional magnetic resonance imaging [10]. However, it is not possible to use this approach outside of the motor and visual cortices because most brain regions do not produce acute neurophysiological or perceptual e ects in response to single pulse TMS.

An alternative technique for identifying participant-speci c stimulation sites on the scalp is the 10–20-electrode system, which was originally designed for positioning EEG electrodes [11]. is approach de nes a grid of positions on the scalp that are separated by 10% or 20% of the distance between anatomical landmarks such as the nasion and the inion. is approach has been used successfully in a large number of brain stimulation studies; however, the mapping of particular 10–20 system locations to speci c brain areas can vary across participants [12].

Another alternative is to use structural and functional brain imaging techniques to localize speci c brain areas in individuals with millimetre resolution. A number of frameless stereotactic navigation systems exist for real-time coregistration of a participant to their own MRI images. Tools such as a "pointer" or a TMS coil can also be registered within the volume. ese systems typically involve ultrasound devices or infrared cameras and a number of reference targets mounted on the head and NIBS apparatus. When used in combination with structural and functional MRI images these "neuronavigation" systems allow for precise identi cation of the scalp position corresponding to a particular brain area [13].

e combination of brain imaging and a neuronavigation system is the current gold standard in the eld of NIBS [14] and may improve the results of NIBS-based therapeutic interventions [15–20]; however, there are some disadvantages. ese include di culty in using these systems for studies of posterior brain areas that can fall outside of the neuronavigation system's eld of view and, most importantly, the high cost of these systems, which can exceed $50,000. Techniques have been described that allow NIBS to be targeted using generic MRI datasets [21] or when structural but not functional MRI data are available for individual participants [22]. Furthermore, techniques for identifying optimal scalp locations for stimulation based on individual participant's neuroanatomy are also available [23]. However, each of these approaches requires the use of a neuronavigation system. Here we describe a technique that allows the use of individual structural and functional MRI to guide NIBS in the absence of a neuronavigation system. e approach is based on vectors drawn on a mesh that is morphed to participant-speci c MRI data. ese mesh vectors are then transposed to the participant's head by converting them to head measurements anchored to anatomical landmarks. We report comparisons between measurements made using our technique and actual head measurements. We also give an example of how the technique can be used in combination with fMRI to localize a stimulation site for visual area V5 in a single subject. Visual area V5 was chosen for this example as it can be readily localized using fMRI and the corresponding scalp position cannot be identi ed based on a single anatomical landmark. erefore, a number of measurements

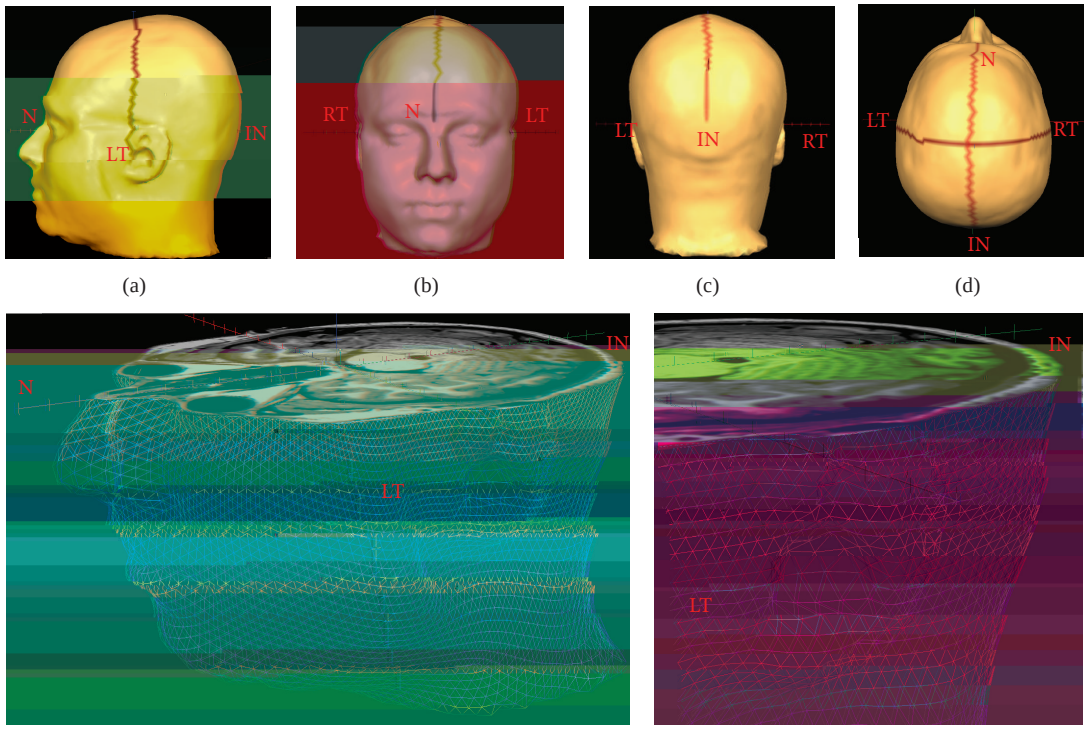
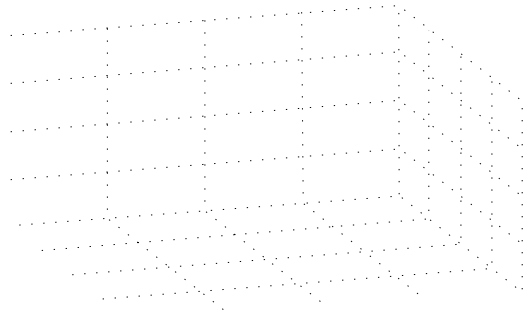
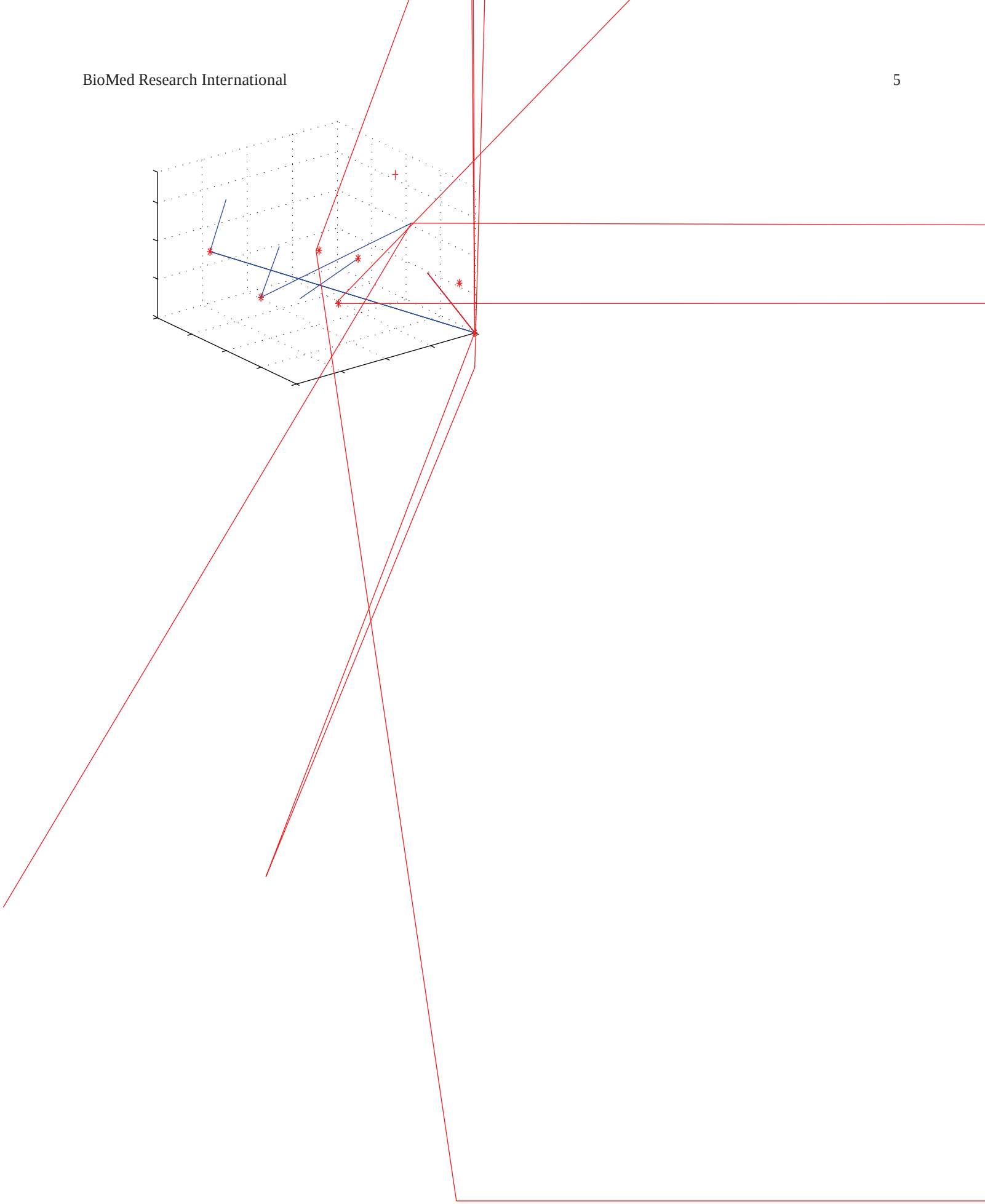
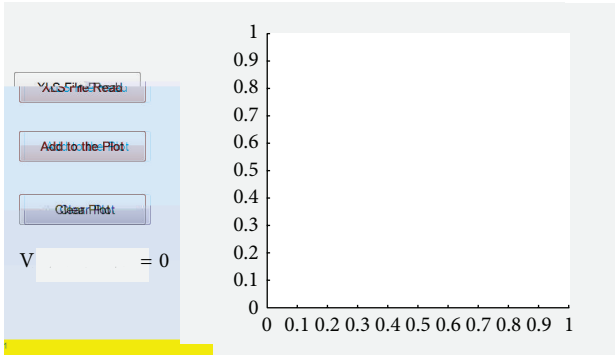


Figure 1: A 3D mesh morphed to the structural MRI data of a representative participant. Panels (a)–(d) show the anatomical landmarks that were used as anchor points for scalp distance calculations marked on a T1-volume surface mesh created using Brain Voyager. N: nasion, RT and LT: right and le tragi, respectively, and IN: inion. e lines connecting the anatomical landmarks are "patches of interest" (POIs) drawn in Brain Voyager that link adjacent triangles in the mesh. Panels (e) and (f) show close-up views of the mesh without the surface coloring. e mesh has been cut axially at the level of the inion. e smooth surface of the head is represented using triangular elements and each of these elements is de ned by its tricorners.

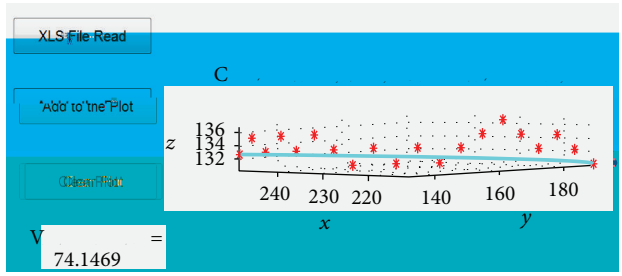
subroutines within Brain Voyager. A general linear analysis was conducted and the results were visualized as t-maps on the anatomical image. Area V5 was identi ed as a



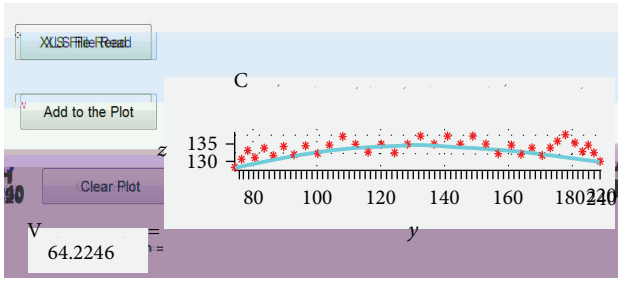



Add to the Plot
V
= 0
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

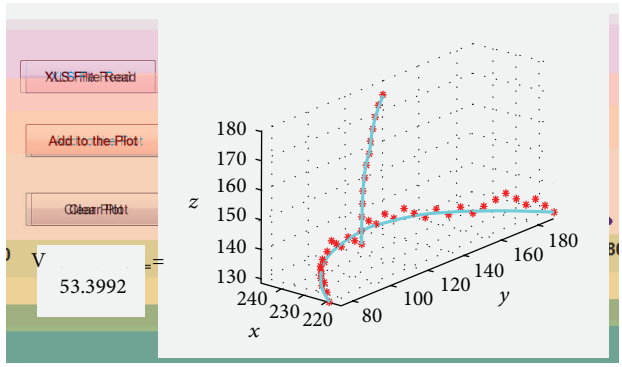
(a)


XLS File Read
Add to the Plot
C
z
136
134
132
240 230 220
x
140 160 180
y
V
=
74.1469

(b)


Add to the Plot
Clear Plot
C
z
135
130
80 100 120 140 160 180
y
V
=
64.2246

(c)


Add to the Plot
V
=
53.3992
180
170
160
150
140
130
z
240 230 220
x
80 100 120 140 160 180
y

(d)

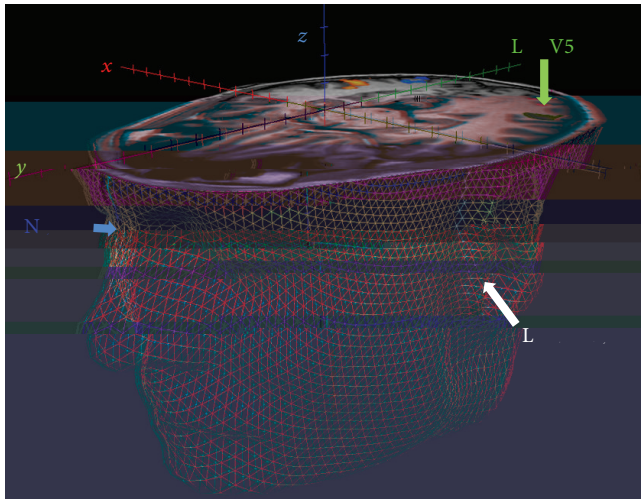


Figure 5: Localization of a scalp position above V5 in the le hemisphere. e axial cut through the Brain Voyager mesh was positioned to reveal the most active voxel in le V5. e lines drawn on the mesh show the POIs that were used to identify the scalp location corresponding to le V5. Blue: nasion to transverse plane, white: tragus to transverse plane, red: intersection of nasion vector and transverse plane to intersection of tragus vector and transverse plane, and green: extension of the vector to the scalp position above area V5. Orange regions indicate areas of functional activation in response to the V5 localization scans. See the main text for a detailed description of this procedure.

not supported. is issue is also relevant to the use of neuronavigation systems. Selection of the optimal stimulation site is a complex process as the electrical current generated by NIBS techniques interacts with the head and brain anatomy in ways that are unique to each participant [33–35]. A number of techniques for identifying optimal NIBS sites based on MRI data have been developed. ese could be combined with our approach for transposing stimulation sites to the head to further improve the targeting of NIBS when neuronavigation systems are not available.

e authors declare that there is no con ict of interests regarding the publication of this paper.

A

is work was supported by grants from Marsden Fund of the Royal Society of New Zealand to Ehsan Vaghe and from the Health Research Council, University of Auckland, Faculty Development Research Fund, and Auckland Medical Research Foundation to Benjamin ompson.

[1] M. Hallett, "Transcranial magnetic stimulation: a primer," *N* , vol. 55, no. 2, pp. 187–199, 2007.

[2] M. A. Nitsche and W. Paulus, "Excitability changes induced in the human motor cortex by weak transcranial direct current stimulation," *J P* , vol. 527, no. 3, pp. 633–639, 2000.

[3] M. C. Ridding and J. C. Rothwell, "Is there a future for therapeutic use of transcranial magnetic stimulation?" *N R N* , vol. 8, no. 7, pp. 559–567, 2007.

[4] J. A. Williams, M. Imamura, and F. Fregni, "Updates of the use of non-invasive brain stimulation in physical and rehabilitation medicine," *J R M* , vol. 41, no. 5, pp. 305–311, 2009.

[5] M. A. Nitsche, S. Doemkes, T. Karaköse et al., "Shaping the e ects of transcranial direct current stimulation of the human motor cortex," *J N* , vol. 97, no. 4, pp. 3109–3117, 2007.

[6] J. Ruohonen and J. Karhu, "Navigated transcranial magnetic stimulation," *N C* , vol. 40, no. 1, pp. 7–17, 2010.

[7] A. T. Barker, R. Jalinous, and I. L. Freeston, "Non-invasive magnetic stimulation of human motor cortex," *L* , vol. 1, no. 8437, pp. 1106–1107, 1985.

[8] T. Kammer, "Phosphenes and transient scotomas induced by magnetic stimulation of the occipital lobe: their topographic relationship," *N* , vol. 37, no. 2, pp. 191–198, 1998.

[9] L. M. Stewart, V. Walsh, and J. C. Rothwell, "Motor and phosphene thresholds: a transcranial magnetic stimulation correlation study," *N* , vol. 39, no. 4, pp. 415–419, 2001.

[10] B. ompson, C. Aaen-Stockdale, L. Koski, and R. F. Hess, "A double dissociation between striate and extrastriate visual cortex for pattern motion perception revealed using rTMS," *H B M* , vol. 30, no. 10, pp. 3115–3126, 2009.

[11] H. H. Jasper, " e ten twenty electrode system of the international federation," *E C N* , vol. 10, pp. 371–375, 1958.

[12] U. Herwig, P. Satrapi, and C. Schönfeldt-Lecuona, "Using the international 10-20 EEG system for positioning of transcranial magnetic stimulation," *B T* , vol. 16, no. 2, pp. 95–99, 2003.

[13] U. Herwig, K. Kölbel, A. P. Wunderlich et al., "Spatial congruence of neuronavigated transcranial magnetic stimulation and functional neuroimaging," *C N* , vol. 113, no. 4, pp. 462–468, 2002.

[14] A. T. Sack, R. C. Kadosh, T. Schuhmann, M. Moerel, V. Walsh, and R. Goebel, "Optimizing functional accuracy of TMS in cognitive studies: a comparison of methods," *J C N* , vol. 21, no. 2, pp. 207–221, 2009.

[15] C. Schönfeldt-Lecuona, J.-P. Lefaucheur, L. Cardenas-Morales, R. C. Wolf, T. Kammer, and U. Herwig, " e value of neuronavigated rTMS for the treatment of depression," *N C* , vol. 40, no. 1, pp. 37–43, 2010.

[16] T. Wagner, F. Fregni, S. Fecteau, A. Grodzinsky, M. Zahn, and A. Pascual-Leone, "Transcranial direct current stimulation: a computer-based human model study," *N I* , vol. 35, no. 3, pp. 1113–1124, 2007.

[17] T. Wagner, A. Valero-Cabre, and A. Pascual-Leone, "Noninvasive human brain stimulation," *A R B E* , vol. 9, pp. 527–565, 2007.

[18] A. Datta, M. Bikson, and F. Fregni, “Transcranial direct current stimulation in patients with skull defects and skull plates: high-resolution computational FEM study of factors altering cortical current ow,” *N I* , vol. 52, no. 4, pp. 1268–1278, 2010.

[19] F. Fregni and A. Pascual-Leone, “Technology insight: non-invasive brain stimulation in neurology—perspectives on the therapeutic potential of rTMS and tDCS,” *N C P N* , vol. 3, no. 7, pp. 383–393, 2007.

[20] P. C. Miranda, P. Faria, and M. Hallett, “What does the ratio of injected current to electrode area tell us about current density