Development of a vibrotactile stimulation system for cognitive rehabilitation

Master Thesis

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Schlagwörter: Schlagwort 1, Schlagwort 2, Schlagwort 3, Schlagwort 4, Schlagwort 5

Abstract

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Keywords: Keyword 1, Keyword 2, Keyword 3, Keyword 4, Keyword 5

Contents

1 Introduction

1.1 Motivation and Problem Statement

Dementia is one of the greatest medical and social challenges of the 21st century. More than 55 million people are affected worldwide - and the trend is rising [1], [2]. Despite advances in medication, treatment remains limited, particularly in terms of cognitive abilities.

Non-pharmacological interventions are therefore increasingly coming into focus [3]. Of particular interest are sensory-based approaches such as vibrotactile stimulation, which can activate specific areas of the brain via targeted stimuli. Initial animal studies show positive effects of 40 Hz stimulation on the reduction of amyloid deposits and on cognitive performance [4], [5], [6].

1.2 Objectives of the Thesis

The aim of this work is to develop a technical system for implementing such stimulation methods. The focus is on a precise, reproducible actuator system that is suitable for applications in the field of cognitive rehabilitation.

1.3 Structure of the Thesis

This work is theoretically and technically oriented and therefore begins with a chapter on the necessary basics. The aim is to provide the medical and technological background knowledge required to understand the system developed.

2 Theoretical Background

2.1 Neurodegenerative Diseases with Cognitive Impairmentss

Neurodegenerative diseases such as Alzheimer's disease and Parkinson's disease are among the most common causes of cognitive impairment in old age. They are characterized by the progressive loss of neuronal functions and structures, which in the long term leads to significant impairments in memory, attention, executive functions and coping with everyday life [7].

2.1.1 Alzheimer's Disease

Alzheimer's disease is the most common form of dementia worldwide and affects over 55 million people, according to the Alzheimer's Association [1]. It is characterized by the pathological deposition of proteins such as amyloid-β-plaques and τ-protein-related neurofibrils in the brain, which leads to the progressive death of nerve cells [8].

Directly recognizable symptoms and complaints begin with a deterioration in episodic memory, a part of long-term memory that is responsible for remembering personal experiences. As the disease progresses, there are deficits in language, orientation and judgment. The disease is long-lasting and progressive and leads to complete dependence on care in later stages [2].

2.1.2 Parkinson's Disease

Parkinson's disease is primarily known as a movement disorder, but cognitive symptoms are also common. Around $30\,\%$ to $40\,\%$ of those affected develop Parkinson's dementia over the course of the disease [9]. Deficits in attention control, executive functions and visual-spatial perception are typical, while memory is often less severely affected at the beginning [10].

The disease occurs because there is too little dopamine in the brain. The reason for this is the death of nerve cells in a certain area of the brain called the *substantia nigra*. In addition, so-called Lewy bodies, which are pathological protein deposits in the nerve cells, can contribute to the development of cognitive symptoms [11].

2.1.3 Cognitive Deficits and Functional Impact

Cognitive impairments in neurodegenerative diseases affect central functions such as memory, attention, language, visual processing and executive abilities [7]. These deficits have a direct impact on the everyday life of those affected - for example, when taking medication independently, handling money, social contacts or spatial orientation [12]. In addition to these practical limitations, there are often emotional and psychosocial burdens. Frustration, depressive moods and social isolation are not uncommon and increase the pressure on both those affected and their personal environment.

This makes the early detection of cognitive symptoms all the more important. It forms the basis for targeted interventions and rehabilitation measures that aim to maintain the patient's independence and quality of life for as long as possible [13].

2.2 Cognitive Rehabilitation: Concepts, Methods, and Target Groups

Multidisziplinäre Ansätze [3]

EEG-Biomarker wie der Brain Symmetry Index (BSI) und der Laterality Coefficient (LC) erlauben eine objektive Bewertung des funktionellen Zustands des Gehirns. Die EEG-Analyse ermöglicht eine individualisierte Rehabilitationssteuerung, indem sie Veränderungen in der Hirnaktivität erfasst – insbesondere im Zusammenhang mit Motor Imagery, einer etablierten kognitiven Rehabilitationsmethode. Die Zielgruppe der Studie sind Schlaganfallpatienten, die oft sowohl motorische als auch kognitive Beeinträchtigungen aufweisen.

[14]

Table 2.1 ergleich verschiedener Studien zur taktilen niederfrequenten Vibration in der Demenzbehandlung

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

2.3 Vibrotactile Stimulation: Principles and Therapeutic Applications

[14]

[15, 16, 17, 18, 19, 20, 21, 22, 23]

2.4 Actuation Technologies for Haptic Feedbacks

40 Hz & Gamma Frequenzen, [24] [4] [5] [6] zeigen neurobiologische Wirkung

2.5 Voice Coil Actuators for Vibrotactile Stimulation

EEG & Wearables [25] [26] [27] [28] über EEG-Tech, BCI, und mobile Erfassung

2.6 Overview of Existing Vibrotactile Stimulation Systems

3 Analysis of the Current VCA-Based System

3.1 Overview of the Current VCA System

This section provides an overview of the existing Voice Coil Actuator (VCA)-based setup. The System consists of seven main parts.

- Spring frame (Minimizing the loss of vertical motion transmitted to the node)
- Magnet Housing (fixed Magnetic field is always formed)
- Bobbin Coil (Magnetic field is formed only when current flows)
- Node (Transmitting vertical motion directly to the human body as sound and vibration)
- Node screw (fixes the node to the bobbin coil)
- Rubber frame (Suppresses vibration from the body from being transmitted to the outside world)
- Connection PCB (Take the analog signal from the AMP and apply it to the bobbin coil)

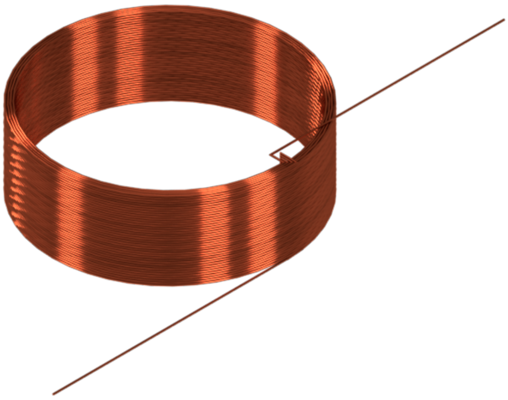
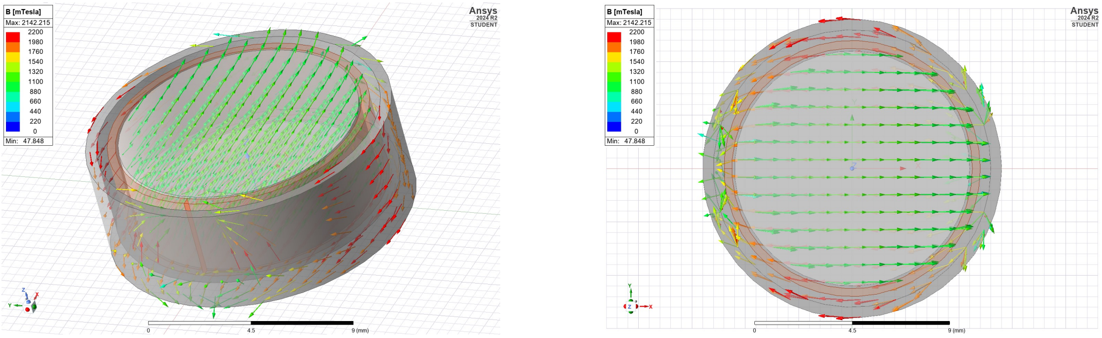


Figure 3.1 coil model



(a) **(b)**

Figure 3.2 Ansys simulation of the B-field in the Magnet Housing
(a) VCA in iso view (b) VCA in top view

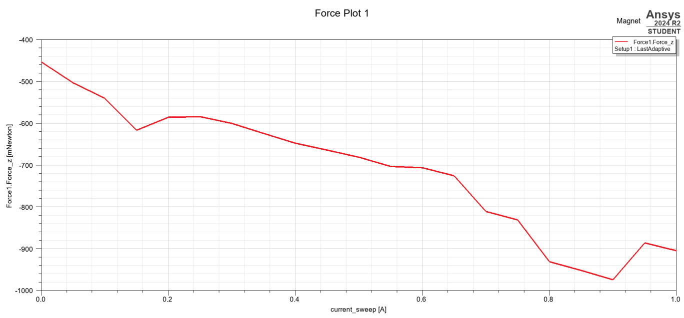


Figure 3.3 Force Plot

3.2 Dynamic Behavior: Frequency Measurement

3.2.1 Objective

3.2.2 Measurement Setup

3.2.3 Results & Interpretation

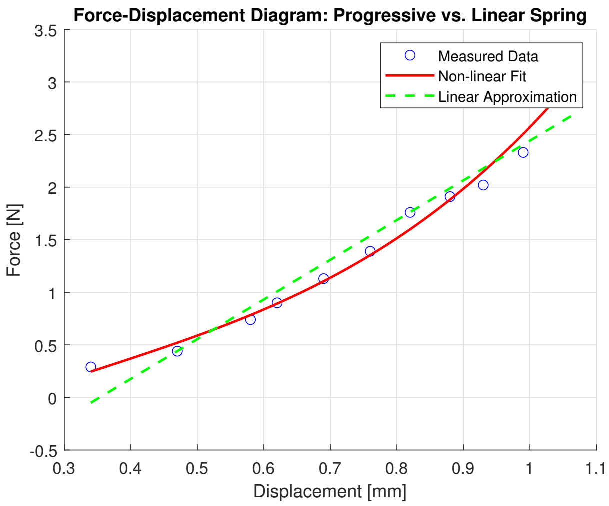


Figure 3.4 SpringTest

3.3 Limitations and Identified Challenges

4 Modify

5 Evaluation

6 Conclusion

Bibliography

[1] A. Association, “Alzheimer’s Association 2025 Alzheimer’s Disease Facts and Figures.”

[2] World Health Organization, *Global Status Report on the Public Health Response to Dementia*, 1st ed. Geneva: World Health Organization, 2021.

[3] C. Zucchella, E. Sinforiani, S. Tamburin, A. Federico, E. Mantovani, S. Bernini, R. Casale, and M. Bartolo, “The Multidisciplinary Approach to Alzheimer’s Disease and Dementia. A Narrative Review of Non-Pharmacological Treatment,” *Frontiers in neurology*, vol. 9, p. 1058, 2018.

[4] A. J. Mably and L. L. Colgin, “Gamma oscillations in cognitive disorders,” *Current opinion in neurobiology*, vol. 52, pp. 182–187, 2018.

[5] H. F. Iaccarino, A. C. Singer, A. J. Martorell, A. Rudenko, F. Gao, T. Z. Gillingham, H. Mathys, J. Seo, O. Kritskiy, F. Abdurrob, C. Adaikkan, R. G. Canter, R. Rueda, E. N. Brown, E. S. Boyden, and L.-H. Tsai, “Gamma frequency entrainment attenuates amyloid load and modifies microglia,” *Nature*, vol. 540, no. 7632, pp. 230–235, 2016.

[6] A. J. Martorell, A. L. Paulson, H.-J. Suk, F. Abdurrob, G. T. Drummond, W. Guan, J. Z. Young, D. N.-W. Kim, O. Kritskiy, S. J. Barker, V. Mangena, S. M. Prince, E. N. Brown, K. Chung, E. S. Boyden, A. C. Singer, and L.-H. Tsai, “Multi-sensory Gamma Stimulation Ameliorates Alzheimer’s-Associated Pathology and Improves Cognition,” *Cell*, vol. 177, no. 2, pp. 256–271.e22, 2019.

[7] P. D. Harvey, “Domains of cognition and their assessment,” *Dialogues in clinical neuroscience*, vol. 21, no. 3, pp. 227–237, 2019.

[8] B. Dubois, H. Hampel, H. H. Feldman, P. Scheltens, P. Aisen, S. Andrieu, H. Bakardjian, H. Benali, L. Bertram, K. Blennow, K. Broich, E. Cavedo, S. Crutch, J.-F. Dartigues, C. Duyckaerts, S. Epelbaum, G. B. Frisoni, S. Gauthier, R. Genthon, A. A. Gouw, M.-O. Habert, D. M. Holtzman, M. Kivipelto, S. Lista, J.-L. Molinuevo, S. E. O’Bryant, G. D. Rabinovici, C. Rowe, S. Salloway, L. S. Schneider, R. Sperling, M. Teichmann, M. C. Carrillo, J. Cummings, and C. R. Jack, “Preclinical Alzheimer’s disease: Definition, natural history, and diagnostic criteria,” *Alzheimer’s & dementia : the journal of the Alzheimer’s Association*, vol. 12, no. 3, pp. 292–323, 2016.

[9] C. C. Janvin, D. Aarsland, and J. P. Larsen, “Cognitive predictors of dementia in Parkinson’s disease: a community-based, 4-year longitudinal study,” *Journal of geriatric psychiatry and neurology*, vol. 18, no. 3, pp. 149–154, 2005.

[10] M. Emre, D. Aarsland, R. Brown, D. J. Burn, C. Duyckaerts, Y. Mizuno, G. A. Broe, J. Cummings, D. W. Dickson, S. Gauthier, J. Goldman, C. Goetz, A. Korczyn, A. Lees, R. Levy, I. Litvan, I. McKeith, W. Olanow, W. Poewe, N. Quinn, C. Sampaio, E. Tolosa, and B. Dubois, "Clinical diagnostic criteria for dementia associated with Parkinson's disease," *Movement disorders : official journal of the Movement Disorder Society*, vol. 22, no. 12, pp. 1689–707; quiz 1837, 2007.

[11] L. V. Kalia and A. E. Lang, "Parkinson's disease," *Lancet (London, England)*, vol. 386, no. 9996, pp. 896–912, 2015.

[12] *Diagnostic and statistical manual of mental disorders: DSM-5*, 5th ed. Washington, D.C.: American Psychiatric Publishing, 2013.

[13] R. C. Petersen, R. O. Roberts, D. S. Knopman, B. F. Boeve, Y. E. Geda, R. J. Ivnik, G. E. Smith, and C. R. Jack, "Mild cognitive impairment: ten years later," *Archives of neurology*, vol. 66, no. 12, pp. 1447–1455, 2009.

[14] E. A. Campbell, J. Kantor, L. Kantorová, Z. Svobodová, and T. Wosch, "Tactile Low Frequency Vibration in Dementia Management: A Scoping Review," *Frontiers in psychology*, vol. 13, p. 854794, 2022.

[15] A. Clements-Cortes, H. Ahonen, M. Evans, M. Freedman, and L. Bartel, "Short-Term Effects of Rhythmic Sensory Stimulation in Alzheimer's Disease: An Exploratory Pilot Study," *Journal of Alzheimer's disease : JAD*, vol. 52, no. 2, pp. 651–660, 2016.

[16] M. Heesterbeek, E. A. van der Zee, and M. J. G. van Heuvelen, "Feasibility of Three Novel Forms of Passive Exercise in a Multisensory Environment in Vulnerable Institutionalized Older Adults with Dementia," *Journal of Alzheimer's disease : JAD*, vol. 70, no. 3, pp. 681–690, 2019.

[17] F. M. H. Lam, L. R. Liao, T. C. Y. Kwok, and M. Y. C. Pang, "Effects of adding whole-body vibration to routine day activity program on physical functioning in elderly with mild or moderate dementia: a randomized controlled trial," *International journal of geriatric psychiatry*, vol. 33, no. 1, pp. 21–30, 2018.

[18] A. A. Clair and B. Bernstein, "The Preference for Vibrotactile Versus Auditory Stimuli in Severely Regressed Persons with Dementia of the Alzheimer's Type Compared to Those with Dementia due to Alcohol Abuse," *Music Therapy Perspectives*, vol. 11, no. 1, pp. 24–27, 1993.

[19] K.-H. Kim and H.-B. Lee, "The effects of whole body vibration exercise intervention on electroencephalogram activation and cognitive function in women with senile dementia," *Journal of exercise rehabilitation*, vol. 14, no. 4, pp. 586–591, 2018.

[20] A. Clements-Cortes, L. Bartel, H. Ahonen, M. Freedman, M. Evans, and D. Tang-Wai, "Can Rhythmic Sensory Stimulation Decrease Cognitive Decline in Alzheimer's Disease?: A Clinical Case Study," *Music and Medicine*, vol. 9, no. 3, p. 174, 2017.

[21] C. Mercado and E. Mercado, “A Program Using Environmental Manipulation, Music Therapy Activities, and the Somatron(C) Vibroacoustic Chair To Reduce Agitation Behaviors of Nursing Home Residents with Psychiatric Disorders,” *Music Therapy Perspectives*, vol. 24, no. 1, pp. 30–38, 2006.

[22] A. Clements-Cortes, L. Bartel, H. Ahonen, and M. Freedman, “The Potential of Rhythmic Sensory Stimulation Treatments for Persons with Alzheimer’s Disease,” *Music and Medicine*, vol. 9, no. 3, p. 167, 2017.

[23] A. Clements-Cortes and L. Bartel, “Long-Term Multi-Sensory Gamma Stimulation of Dementia Patients: A Case Series Report,” *International journal of environmental research and public health*, vol. 19, no. 23, 2022.

[24] Y. K. Reiko Tutida, “Low-Frequency, Whole Body Vibration Induced Neurite Outgrowth by Pc12m3 Cells with Impaired Nerve Growth Factor-Induced Neurite Outgrowth,” *Journal of Novel Physiotherapies*, vol. 05, no. 01, 2014.

[25] C. Guger, G. Krausz, B. Z. Allison, and G. Edlinger, “Comparison of dry and gel based electrodes for p300 brain-computer interfaces,” *Frontiers in neuroscience*, vol. 6, p. 60, 2012.

[26] C. Guger, R. Spataro, B. Z. Allison, A. Heilinger, R. Ortner, W. Cho, and V. La Bella, “Complete Locked-in and Locked-in Patients: Command Following Assessment and Communication with Vibro-Tactile P300 and Motor Imagery Brain-Computer Interface Tools,” *Frontiers in neuroscience*, vol. 11, p. 251, 2017.

[27] M. Sebastián-Romagosa, E. Udina, R. Ortner, J. Dinarès-Ferran, W. Cho, N. Murovec, C. Matencio-Peralba, S. Sieghartsleitner, B. Z. Allison, and C. Guger, “EEG Biomarkers Related With the Functional State of Stroke Patients,” *Frontiers in neuroscience*, vol. 14, p. 582, 2020.

[28] R. Xu, R. Spataro, B. Z. Allison, and C. Guger, “Brain-Computer Interfaces in Acute and Subacute Disorders of Consciousness,” *Journal of clinical neurophysiology : official publication of the American Electroencephalographic Society*, vol. 39, no. 1, pp. 32–39, 2022.

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