# Biofeedback in Breast Cancer Rehabilitation: Applying the WHO ICF Core Set to Identify Opportunities and Recommendations

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***Abstract*—Digital biofeedback technologies are used in physical rehabilitation to improve motor learning and enhance engagement with therapies, but they are unfrequently used in breast cancer rehabilitation. Digital biofeedback interventions should be custom-made for the specific breast cancer context. The WHO ICF Core Set for Breast Cancer describes this context by itemising the biopsychosocial and environmental factors associated with breast cancer. We analysed this Core Set to identify opportunities for biofeedback intervention, and to make recommendations for successful, inclusive design of digital biofeedback interventions in breast cancer rehabilitation. Impairments of strength, joint movement and upper limb function present opportunities for the development of digital biofeedback interventions. Factors related to sensory loss, lymphoedema, chemotherapy-related cognitive dysfunction and fatigue should be considered when designing and evaluating biofeedback systems.**

***Keywords-biofeedback, breast cancer, rehabilitation, technology***

## I. INTRODUCTION

Rehabilitation technology and digital interventions with sensor-enabled biofeedback are increasingly used as adjuncts to physiotherapy treatment as they can improve motor learning, enhance engagement with therapy and facilitate data-driven models of care [1,2]. Biofeedback in rehabilitation is the process of providing patients with additional information regarding a specific body function, allowing them to then self-regulate this function [3,4]. An external sensor collects biological information, which is then relayed back to the user. To ensure the biofeedback intervention suits a particular user or task, several features should be considered. For example, biofeedback can be of a visual, audio, haptic or multi-modal format. Additionally, information can be represented either directly, for example the visualisation of heart rate as beats per minute, or in an abstract manner, such as through a gamified interface or sonification of movement [1,5].

Digital biofeedback interventions [DBI] are widely used by physiotherapists in physical rehabilitation, and are well-established in the fields of gait re-education, balance training, musculoskeletal rehabilitation and stroke rehabilitation [6–8]. In breast cancer care, biofeedback is commonly used in radiation therapy [9,10], and has been applied as a psychological intervention [11], but only a few studies have investigated using it in physical rehabilitation [12,13]. Physical rehabilitation, including physiotherapy treatment, is acknowledged as a key component of care during treatment for breast cancer [14,15], addressing impairments such as joint pain or stiffness, lymphoedema, and local or global muscle weakness. These impairments occur in other medical conditions, such as CVA and osteoarthritis, where they can be treated with already-existing biofeedback interventions. However, the personal, medical, social and environmental contexts surrounding these impairments can be vastly different in breast cancer, requiring custom-made biofeedback interventions for this condition. To inform the development of such interventions, thorough recommendations which consider the full biopsychosocial and environmental contexts of individuals with breast cancer are needed.

The World Health Organization's [WHO] International Classification of Functioning, Disability and Health [ICF] is a globally accepted framework for understanding and describing functioning and disability for clinical, research, public health and policy uses [16,17]. The structure of the ICF [figure 1], with its four components each consisting of many pre-defined categories, covers the full biopsychosocial spectrum of health and allows it to act as a common international language for describing the impact of a health condition.

Using this framework, Brach et al. [18] developed a list of essential categories that are relevant for breast cancer. This list, called the ICF Core Set for Breast Cancer, was then validated from the perspective of physiotherapists by Glaessal et al. [19] and from the perspective of women with breast cancer by Cooney et al. [20]. These studies recommended the inclusion of several additional categories to the ICF Core Set, resulting in a fully comprehensive set of factors to consult when designing a biofeedback intervention for use in breast cancer rehabilitation. Notably, these factors will not be present in all patients, and their presence will vary greatly between individuals with breast cancer.

This paper firstly aims to analyse the ICF Core Set for Breast Cancer [comprising both the original Core Set and the recommendations from Glaessel et al. and Cooney et al.] to identify the opportunities for biofeedback-based interventions. We will then make recommendations for the design of biofeedback interventions in breast cancer rehabilitation using the ICF component headings i. Body Function and Body Structure, ii. Activity and Participation, iii. Environmental Factors.

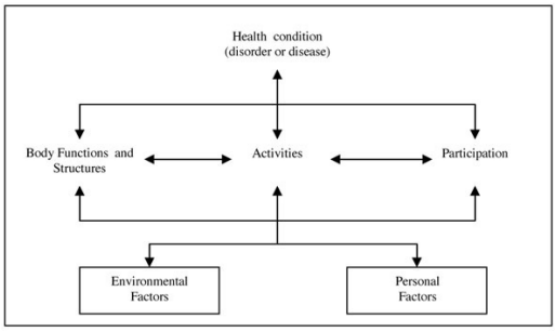



Figure 1: The components 'Body Functions and Structures', 'Activities and Participation' 'Environmental Factors' and 'Personal Factors' are made up of over 1,400 different categories covering manifold aspects of health.

## II. Categories and related impairments appropriate for biofeedback interventions

The complex presentation of physical symptoms in breast cancer requires a management plan that reflects this complexity. This often requires multi-disciplinary or multi-modal treatment plans, of which a biofeedback intervention is just one component. The ICF categories, and their related impairments or limitations, which could be treated with a DBI as part of a holistic management plan are summarised in table 1. DBIs are effective in the treatment of many of these impairments in different health conditions[21–24]. To develop DBIs specific to breast cancer rehabilitation, the latest evidence-based methods of muscle strengthening, cardiovascular training, mobility training, lymphoedema management, functional rehabilitation, patient education and self-management practices should be combined with appropriate technological systems, while following the recommendations in sections III, IV, and V of this paper.

## III. Recommendations: Body Function and Body Structure

### *A. A. Mental Functions*

Patients with chemotherapy-related cognitive dysfunction can find tasks which require attention and working memory challenging [25]. Biofeedback can provide patients with the information they may have difficulty recalling, by prompting exercise technique, or providing reminders to do exercises. Rehabilitation is an emotionally demanding process, and DBIs should consider the patient's energy levels and emotional state. Technology can facilitate users to reach their rehabilitation goals, without creating undue pressure, frustration or other negative emotional states. This can be achieved through clear and intuitive systems, combined with goal-setting features which can be adjusted by the user to meet their changing needs. Systems should avoid complex or abstract 3D visualisation and negative messages.

Individuals with breast cancer may have experienced physical changes due to cancer treatment and have concerns about body image [26]. Exercise biofeedback systems often use an avatar to represent the user and simulates their motions during exercise [26,27]. A choice of avatars which have been designed with and approved by users will provide a more representative user experience

TABLE 1
Impairments appropriate for biofeedback interventions

| ICF Category | Impairment |
|---|---|
| Sensation of pain | Pain – shoulder girdle and arm, global |
| Functions of lymphatic vessels | Lymphoedema, impaired lymphatic function |
| Exercise tolerance function | Poor exercise tolerance, fatigue |
| Weight maintenance functions | Weight gain / loss, difficulty managing weight |
| Mobility of joint functions | Reduced joint range of movement, joint stiffness |
| Mobility of bone functions | Reduced joint range of movement, joint stiffness |
| Muscle endurance functions | Muscle weakness upper limb, muscle weakness global, poor exercise tolerance, fatigue |
| Sensations related to muscles and movement functions | Muscle stiffness |
| Structure of upper extremity | Muscle loss, posture |
| Hand and arm use | Reduced upper limb [UL] function, difficulty with activities of daily living using UL |
| Fine hand use | Reduced power, lymphoedema |

### *B. Sensory Functions*

Impairments of touch, hearing and seeing functions can occur during treatment for breast cancer [20,29]. Accessibly designed biofeedback can compensate for sensory loss, allowing all users to benefit equally from the technology [27,28]. Sensory modes should be easily interchangeable, so that a user with visual impairment may receive audio feedback, and vice-versa. Where visual feedback is required, this communication can be reinforced using conventional metaphors such as applying a green or red colour to indicate when is goal is, or is not, achieved. Use of dimensions of sound (e.g. volume, pitch, tone) and vision (e.g. contrast sensitivity, visual acuity, colour perception) should be explored so information is relayed with maximum clarity.

Chemotherapy-induced peripheral neuropathy is a commonly occurring long-term side effect of breast cancer treatment, characteristic by numbness, pins and needles and pain in the hands and feet [29]. Manual data entry and other tasks which require fully intact peripheral somatosensory systems should be avoided. Post-operative pain may limit a patient's ability to complete rehabilitation exercises and to interact with the DBI [30]. Inclusion of a pain assessment tool in the system can enable the feedback to be adapted appropriately to the patient's pain level. Provocation of pain can be avoided by using external sensors which are lightweight, non-invasive and suitably located on the body. Garments imbedded with miniature movement sensors have been used in ergonomic biofeedback systems for stroke rehabilitation [31], and further studies have utilised the Microsoft Kinect, which contains an RGB camera and depth sensor, thus removing the need for any wearable hardware [32].

### C. Neuromusculoskeletal and Movement Functions

Individuals with breast cancer experience impairments in mobility of joints, muscle power and muscle endurance, especially in the immediate post-operative period [31]. Neuromusculoskeletal functions typically improve post-operatively, but this improvement is not always linear, and patients' abilities fluctuate due to factors such as pain and fatigue [32]. DBIs for breast cancer rehabilitation need to provide personalised feedback, which will be responsive to changes in neuromusculoskeletal abilities. A system which, for example, detects a loss of range of movement and reports this to a patient without considering other contextual factors may cause distress or encourage the patient to push beyond acceptable boundaries. Equally, it may result in abandonment of the system, and possibly the rehabilitation programme, due to loss of trust from the patient. Therefore, it is imperative that these systems meet national regulations for medical devices and that they employ accurate data analytics [32,33]. Crucially, it is recommended that biofeedback systems are prescribed by healthcare professionals and operate as adjuncts to holistic professional treatment.

### D. Immunological and Respiratory Functions

Lymphoedema is prevalent in 5 - 55% of individuals with breast cancer, depending on treatments received [33], and can lead to pain, weakness and numbness in the upper limb, a reduction in upper limb function and a deterioration in quality of life [34]. As mentioned in section iic, DBIs should be responsive to changes in health status and should be used alongside a qualified healthcare professional who can monitor lymphoedema and provide advice as needed. Somatosensory loss and body image concerns which may accompany lymphoedema are discussed in sections iib and iia respectively.

Adjuvant treatments for breast cancer can negatively impact cardio-pulmonary function, causing reduced exercise tolerance [35]. Individuals with breast cancer are recommended to partake in regular exercise to improve the negative physical and psychological sequelae of breast cancer treatment, and biofeedback systems can enhance this by monitoring activity levels, providing positive feedback and promoting goal attainment [36]. The systems should use discreet physiological sensors to monitor heart rate and respiratory rate [22] over time and provide suitable feedback if they exceed, or do not meet, recommended levels. Using the DBI to collect information on rate of perceived exertion during exercise and post-exercise energy levels will provide the patient and healthcare professional with a data set from which to make recommendations for future exercise sessions.

## IV. Recommendations: Activity and Participation

The categories within the 'Activity and Participation' component concern how impairments can lead to limitations in activity and restrictions in participating in all areas of life. Activities involving coordinated, purposeful actions with the arm and hand can be limited. Therefore, external sensors and interface devices must be lightweight and easy to manipulate so as not to further impair a person's ability to participate in exercises. To facilitate activity of rehabilitation in daily life, some users may benefit from biofeedback technology which can sync with their smart phone calendar to deliver scheduled reminders to perform their exercise programme.

Rehabilitation is more meaningful and effective when related to a patient's activity- and participation-related goals. Research using wearable sensors to analyse upper limb movement during activities of daily living in both healthy populations and in neurological conditions has strong potential to be applied to creating BDIs in breast cancer [37–39]. Sport-specific biofeedback has been developed for golf, basketball and rowing [40–42], and this approach can be incorporated into a rehabilitation programme for individuals with breast cancer aiming to return to sports.

## V. Recommendations: Environmental Factors

To minimise disruption and optimise adherence, biofeedback systems should fit into user's physical environments in a natural, unobtrusive manner. An example of this is the use of inertial measurement units in mobile phones for activity recognition [43]. However, while the portability and ubiquity of smart phones is an advantage, allowing for enhanced data collection, their screen size is small and users with visual impairments may benefit from a web application which they can access on a large PC monitor. Healthcare professionals or systems can increase communication with patients by viewing progress, providing feedback, and conducting telerehabilitation sessions remotely through the DBI. This can improve accessibility in instances of geographical, financial or temporal barriers.

## VI. Conclusion

DBIs can be used to enhance physical rehabilitation but have not been yet been widely applied in breast cancer rehabilitation. Biofeedback technologies should be designed specifically for use in the complex biopsychosocial context of breast cancer, as described by the WHO ICF Core Set for Breast Cancer. Impairments in body functions, limitations in activities and participation restrictions can be opportunities for the use of biofeedback, and/or factors to consider when designing DBIs. These recommendations aim to improve usability, enhance engagement with the technology, foster accessibility and ultimately optimise rehabilitation outcomes.

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## References

[1] Sigrist R, Rauter G, Riener R, Wolf P. "Augmented visual, auditory, haptic, and multimodal feedback in motor learning: A review." *Psychometric Bulletin and Review*, vol 20, no 1, pp21–53, 2013. DOI 10.3758/s13423-012-0333-8

[2] Chivacowsky S, Wulf G. "Feedback after good trials enhances learning." *Research Questions in Exercise Sport*, vol 78, no 2, pp 40–7, 2007.

[3] Huang H, Wolf SL, He J. "Recent developments in biofeedback for neuromotor rehabilitation." *Journal of Neuroengineering and Rehabilitation*, vol 3, no 11, 2006. doi:10.1186/1743-0003-3-11

[4] Frank DL, Khorshid L, Kiffer JF, Moravec CS, McKee MG. "Biofeedback in medicine: Who, when, why and how?" Mental Health in Family Medicine, vol 7, no 2, pp85-91, 2010. doi: 10.1002/9780470935538.app4

[5] Timmermans AAA, Seelen HAM, Willmann RD, Kingma H. "Technology-assisted training of arm-hand skills in stroke: concepts on reacquisition of motor control and therapist guidelines for rehabilitation technology design." *Journal of Neuroengineering and Rehabilitation*, vol 6, no 1, pp1-18, 2009.

[6] Chamorro-Moriana G, Moreno AJ, Sevillano JL. "Technology-based feedback and its efficacy in improving gait parameters in patients with abnormal gait: A systematic review." *Sensors*, vol 18, no 142, 2018. doi: 10.3390/s18010142

[7] Stanton R, Ada L, Dean CM, Preston E. "Biofeedback improves activities of the lower limb after stroke: A systematic review." *Journal of Physiotherapy* vol 57, no 3, pp145-55, 2011. doi: 10.1016/S1836-9553[11]70035-2

[8] Ma CZH, Wong DWC, Lam WK, Wan AHP, Lee WCC. "Balance improvement effects of biofeedback systems with state-of-the-art wearable sensors: A systematic review." *Sensors*, vol 16, no 4, pp1-34 2016.

[9] Vikström J, Hjelstuen MHB, Mjaaland I, Dybvik KI. "Cardiac and pulmonary dose reduction for tangentially irradiated breast cancer, utilizing deep inspiration breath-hold with audio-visual guidance, without compromising target coverage breast cancer." *Acta Oncologica*, vol 50, pp42-50, 2011.

[10] Cervino L, Gupta S, Rose MA, Yashar C, Jiang S. "Using surface imaging and visual coaching to improve the reproducibility and stability of deep-inspiration breath hold for left-breast-cancer radiotherapy." *Physics in Medicine & Biology*, vol 54, pp6853-6865, 2009. doi: 10.1088/0031-9155/54/22/007

[11] Omam SSH, Makvand S, Nazemi H. "Biofeedback-assisted relaxation training helps women with breast cancer after mastectomy : Effects of EMG-HRV biofeedback on psychological symptoms." *24thEuropean Congress of Psychiatry*, S779, 2016. doi: 10.1016/j.eurpsy.2016.01.2337

[12] Gabrys L, Sperzel S, Bernhoerster M, Banzer W. "Real-time visual activity feedback for physical activity improvement in breast and colon cancer patients." *Research in Sports Medixine*, vol 25, no 1, pp1-10, 2017.

[13] Keum Soon K, So Woo L, Myoung Sun Y, Smi C, So-Hi K. "Effects of Abdominal Breathing Training Using Biofeedback on Stress, Immune Respone and Quality of Life in Patients with a Mastectomy for Breast Cancer." *Journal of the Korean Academy of Nursing*, vol 35, no 7, pp1295–303, 2005.

[14] Winters-Stone KM, Schwartz AL, Hayes SC. "A Prospective Model of Care for Breast Cancer Rehabilitation." *Cancer*, vol 118, pp2288-99, 2012

[15] NICE. "Early and locally advanced breast cancer." www.nice.org.uk. 2018.

[16] World Health Organisation. "World Report on Ageing and Health." Geneva; 2015. Available from: http://who.int

[17] Üstün TB, Chatterji S, Bickenbach J, Kostanjsek N, Schneider M. "The International Classification of Functioning , Disability and Health: a new tool for understanding disability and health." *Disability and Rehabilitation*, vol 25, pp565-571, 2009. doi: 10.1080/0963828031000137063

[18] Brach M, Cieza A, Stucki G, Füßl M, Cole A, Ellerin BE et al. "ICF Core Sets for breast cancer." *Journal of Rehabilitation Medicine*, vol 36, pp121–7, 2004.

[19] Glaessel A, Kirchberger I, Stucki G, Cieza A. "Does the Comprehensive International Classification of Functioning , Disability and Health [ ICF ] Core Set for Breast Cancer capture the problems in functioning treated by physiotherapists in women with breast cancer ?" *Physiotherapy*, vol 97, no 1, pp33-46, 2011. doi: 10.1016/j.physio.2010.08.010

[20] Cooney M, Galvin R, Connolly E, Stokes E. "The International Classification of Functioning [ICF] Core Set for breast cancer from the perspective of women with the condition." *Disability and Rehabilitation*, vol 35, no 9, pp740-8, 2013.

[21] Huang HY, Lin JJ, Guo YL, Wang WTJ, Chen YJ. "EMG biofeedback "effectiveness to alter muscle activity pattern and scapular kinematics in subjects with and without shoulder impingement." *Journal of Electromyography and Kinesiology*, vol 23, no 1, pp267–74, 2013.

[22] Giggins OM, Persson U, Caulfield B, Tate J, Milner C, Onate J, et al. "Biofeedback in rehabilitation." *Journal of Neuroengineering and Rehabililtation*, vol 10, no 1, p60, 2013. doi: 10.1186/1743-0003-10-60

[23] Choi YL, Kim BK, Hwang YP, Moon OK, Choi WS. "Effects of isometric exercise using biofeedback on maximum voluntary isometric contraction, pain, and muscle thickness in patients with knee osteoarthritis." *Journal of Physical Therapy Science*, vol 27, no 8, pp2439–41, 2015. doi: 10.1589/jpts.27.2439

[24] Correia FD, Nogueira A, Magalhães I, Guimarães J, Moreira M, Barradas I, et al. "Home-based Rehabilitation With A Novel Digital Biofeedback System versus Conventional In-person Rehabilitation after Total Knee Replacement : a feasibility study." *Nature: Scientific Reports*, vol 8, pp–12, 2018.

[25] Jung MS, Zhang M, Askren MK, Berman MG, Peltier S, Hayes DF, et al. "Cognitive dysfunction and symptom burden in women treated for breast cancer : a prospective behavioral and fMRI analysis." *Brain Imaging and Behavior*, vol 11, pp86–97, 2017. doi: 10.1007/s11682-016-9507-8

[26] Paterson C, Lengacher C, Donovan K, Kip K, Tofthagen C. "Body Image in Younger Breast Cancer Survivors: A Systematic Review." *Cancer Nursing*, vol 39, no 1, pp1–29, 2016. doi: 10.1097/NCC.0000000000000251.Body

[27] Ladner RE. "Communication Technologies for People With Sensory Disabilities." *Proceedings of the IEEE*. vol 100, no 4, pp957–73, 2012.

[28] Ladner RE. "Accessible Technology and Models of Disability." *Design and Use of Assistive Technology*. New York: Springer; 2010. p. 25–31.

[29] Brewer J, Morrison G, Dolan E, Fleming G. "Chemotherapy-induced peripheral neuropathy: Current status and progress." *Gynecologic Oncology*, vol 140, no 1, pp176–83, 2016.

[30] Sindhu BS, Shechtman O, Tuckey L. "Validity, Reliability, and Responsiveness of a Digital Version of the Visual Analog Scale." *Journal of Hand Therapy*, vol 24, no 4, pp356-64, 2011. doi:10.1016/j.jht.2011.06.003

[31] Nesvold I-L, Dahl AA, Løkkevik E, Marit Mengshoel A, Fosså SD. "Arm and shoulder morbidity in breast cancer patients after breast-conserving therapy versus mastectomy." *Acta Oncologica*, vol 47, no 5, pp835–42, 2008.

[32] Hidding JT, Beurskens CHG, van der Wees PJ, van Laarhoven HWM, Nijhuis-van der Sanden MWG. "Treatment Related Impairments in Arm and Shoulder in Patients with Breast Cancer: A Systematic Review". *PLoS One*, vol 9, no 5, e96748, 2014. doi: 10.1371/journal.pone.0096748

[33] Shah C, Arthur DW, Wazer D, Khan A, Ridner S, Vicini F. "The impact of early detection and intervention of breast cancer- related lymphedema: a systematic review" *Cancer Medicine*, vol 5, no 6, pp1154-1162, 2016.

[34] Hayes SC, Janda M, Cornish B, Battistutta D, Newman B. "Lymphedema After Breast Cancer : Incidence , Risk Factors, and Effect on Upper Body Function." *Journal of Clinical Oncology*, vol 26, no 2, pp3536-3542, 2019.

[35] Peel AB, Thomas SM, Dittus K, Jones LW, Lakoski SG. "Cardiorespiratory Fitness in Breast Cancer Patients : A Call for Normative Values." *Journal of the American Heart Association*, vol 13, no , pp1–9, 2014.

[36] Beg MS, Gupta A, Stewart T, Rethorst CD. "Promise of Wearable Physical Activity Monitors in Oncology Practice." *Journal of Oncology Practice*, vol 13, no 2, pp82-90, 2017. doi: 10.1200/JOP.2016.016857

[37] Coley B, Jolles BM, Farron A, . "Detection of the movement of the humerus during daily activity." *Medical & Biological Engineering & Computing*, vol 47, pp467–74, 2009. doi: 10.1007/s11517-009-0464-x

[38] Wang Q, Markopoulos P, Yu B, Chen W, Timmermans A. "Interactive wearable systems for upper body rehabilitation: A systematic review." *Journal of Neuroengineering and Rehabililtation*, vol 14, no 1, pp1-21, 2017.

[39] Xiao ZG, Menon C. "Towards the development of a wearable feedback system for monitoring the activities of the upper-extremities." *Journal of Neuroengineering and Rehabilitation*, vol 11, no 2, pp1–13, 2014.

[40] Sarang R, Jahed Motlagh MR, Abbaspour Tehrani A, Pouladian M. "A New Learning Control System for Basketball Free Throws Based on Real Time Video Image Processing and Biofeedback." *Engineering, Technology & Applied Science Research*, vol 8, no 1, pp2405-2411, 2018.

[41] Gorman AJ, Willmott AP, Mullineaux DJ. "The Effects Of Concurrent Biofeedback On Rowing Performance." *35th Conference of the International Society of Biomechanics in Sports*, p671–674, 2017.

[42] Kos A, Umek A. "Wearable training system with real-time biofeedback and gesture user interface." *Personal and Ubiquitous Computing* vol 19, pp989–98, 2015. doi: 10.1007/s00779-015-0886-4

[43] Bisio I, Member S, Delfino A, Lavagetto F, Sciarrone A. "Enabling IoT for In-Home Rehabilitation : Accelerometer Signals Classification Methods for Activity and Movement Recognition". *IEEE Internet of Things Journal*, vol 4, no 1, pp135–46, 2017. doi: 10.1109/JIOT.2016.2628938