Australian Music Therapy Association

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Silveira, T.M., Tamplin, J., Dorsch, S., & Barlow, A.

To cite this article: Silveira, T.M., Tamplin, J., Dorsch, S. & Barlow, A. (2018). Let's Improvise! iPad-based music therapy with functional electrical stimulation for upper limb stroke rehabilitation. *Australian Journal of Music Therapy, 28,* 1- 16. Retrieved from https://www.austmta.org.au/journal/article/let%E2%80%99s-improvise-ipad-based-music-therapy-functional-electrical-stimulation-upper

In plain language:

In the western world, stroke has been identified as the leading cause of disability in adults. Impairment to the arm/hand and depressive symptoms seem to be among the most frequent resultants of stroke. This article describes a collaborative occupational therapy and music therapy intervention for post-stroke arm/hand recovery. The intervention itself combines principles of music therapy with tablet technology and functional electrical stimulation. The implementation of this novel intervention, described in this clinical case report, has implications for benefits to physical and motivational aspects of rehabilitation. Recommendations for further research of this intervention are also discussed.

Clinical case report

Let's Improvise! iPad-based music therapy with functional electrical stimulation for upper limb stroke rehabilitation

Tanya Marie Silveira[1,2], Jeanette Tamplin[1], Simone Dorsch[3] & Anna Barlow[2]

[1] National Music Therapy Research Unit, Faculty of Fine Arts and Music, University of Melbourne, Australia
[2] MetroRehab Hospital, Sydney, Australia
[3] Australian Catholic University, Melbourne, Australia

Abstract
This retrospective clinical case report will examine the implementation of a novel intervention combining a Functional Electrical Stimulation (FES) protocol with an iPad application. A 74-year-old female retired pianist and Professor of Music was admitted to a rehabilitation hospital following a left pontine stroke. On assessment, she was unable to use her right upper limb functionally. Conventional occupational therapy commenced soon after admission and consisted of functional retraining, including FES to the wrist and finger extensors. At week 4, the Registered Music Therapist (RMT) and Occupational Therapist (OT) collaborated to commence a trial of forearm FES in combination with an iPad-based music making application; *ThumbJam*. This application was used to encourage the patient to participate in touch sensitive musical improvisation using the affected hand in an attempt to promote engagement in complex motor patterns and non-verbal expression. Within 3 weeks, the patient was able to use *ThumbJam* without the FES, progressed to the keyboard in 4 weeks and has since commenced independent scales on the piano at home (21 weeks), as well as successful use of the upper limb in Activities of Daily Living (ADLs). On follow up (7 months), the patient reflected on the motivating elements of the intervention that helped her to achieve a functional outcome in her upper limb. This retrospective clinical case report will review the evidence with regard to FES and music therapy, outline the treatment protocol used and make recommendations for future research of "FES+*ThumbJam*" in upper limb stroke rehabilitation.

Keywords: music therapy, stroke, upper limb impairment, collaboration, functional electrical stimulation

Literature Review

Background

In the western world, stroke has been identified as the leading cause of disability in adults (Australian Institute of Health and Welfare, 2016). The number of new and recurrent strokes in Australia was estimated to be more than 56,000 in 2017 alone (Deloitte Access Economics, 2017). Further to this, the estimated total number of people living with

Address correspondence to:
Tanya Marie Silveira
tanya.silveira@gmail.com

the effects of stroke in Australia in 2017 was 475,000 and is set to increase to 1 million by 2050 (Deloitte Access Economics, 2017).

The stroke rehabilitation guidelines recommend a multidisciplinary approach to rehabilitation (Winstein et al, 2016), ideally commencing within 48 hours of stroke onset (Pollack & Disler, 2002). When the stroke survivor is discharged from hospital, they may need to reconsider their career and living situation due to changes in their mobility, which can be emotionally confronting and difficult to process (Pallesen, 2013). Compounding this, the cost of ensuring access to appropriate outpatient rehabilitation and care post discharge from an inpatient hospital rehabilitation service often places a financial burden on the individual and their family (Das et al., 2010).

Stroke

A stroke occurs when there is a disruption of blood supply in the brain (Stroke Foundation Australia, 2018), presenting as either a blood clot (ischemic stroke) or burst vessel (haemorrhagic stroke). As blood contains oxygen and specific nutrients necessary for the functioning of brain cells, this disruption of blood supply results in the death of brain cells at stroke onset (Stroke Foundation Australia, 2018). Depending on the site of stroke onset, there is potential for one or more areas of the brain to be impacted, leading to deficits in emotional regulation, communication, cognition and/or physicality of movement.

The most common consequence of stroke is motor impairment in the form of hemiparesis to the lower limb, upper limb and/or lower face. The term hemiparesis originates from the words “hemi”, meaning “one side”, and “paresis” meaning “weakness”; it is the resultant weakness of one side of the body. This one-sided weakness results from the site of stroke occurring in the opposite hemisphere of the brain; i.e. if the stroke occurred in the left side of the brain, the survivor would have hemiparesis to the right side of the body. As hemiparesis affects 80% of stroke survivors, the rehabilitation of motor function is vital (Thaut, Kenyon, Hurt, McIntosh, & Hoemberg, 2002). Further to this, 50% of stroke survivors with hemiparesis have chronic loss of arm function (Intercollegiate Working Stroke Party, 2016).

When commencing rehabilitation, it is essential to focus upon improving the stroke survivor’s ability to partake in basic ADLs (Legg et al., 2007). Some basic ADLs include bathing/showering, personal hygiene/grooming, dressing, toilet hygiene, functional mobility and self-feeding (Prakoso, Vitriana & Ong, 2016); all of which require the use of the upper limb. The upper limb has a wide range of motion at the joints and is able to co-ordinate movement across many joints, thus promoting the multiple movement patterns required for successful ADL task completion (Gates, Walters, Cowley, Wilken, & Resnik, 2015).

Post-stroke depression has also been identified as a significant and frequent consequence of stroke and is experienced by approximately one-third of stroke survivors (Hackett & Pickles, 2014). Not only is post-stroke depression emotionally debilitating, but it can adversely influence the mortality rate, quality of life and functional recovery of the individual (Paolucci, 2017).

Music therapy in stroke rehabilitation

At present, the main approach to the rehabilitation of the upper limb involves conventional physiotherapy and occupational therapy treatments. Although music therapy is recognised as an allied health profession in

Australia, it is not generally included in standard treatment for stroke rehabilitation. Traditionally, music therapy approaches encourage the individual to access affective and motivational systems in the brain through non-verbal emotional expression (Galińska, 2015). Further to this, when the individual engages in creating music, the immediate auditory feedback may also motivate repetitive engagement with the musical stimulus (La Gasse & Thaut, 2012).

Baker and Tamplin (2006) highlight the role of music therapy in neurorehabilitation by describing specific music therapy interventions relevant to impairments within the rehabilitation setting. Though stroke-specific interventions are not explicitly identified in this resource, Baker and Tamplin (2006) extensively outline intervention protocols for general motor rehabilitation, which can also be implemented in stroke rehabilitation. Thaut & McIntosh (2014) identify two main neurologic music therapy techniques relevant for upper limb stroke rehabilitation: 1) therapeutic instrumental music performance; and 2) patterned sensory enhancement. Therapeutic instrumental music performance draws upon functional movement patterns using musical instruments to encourage the individual to engage in repetitive, cyclic movement of the paretic limb, with musical support (Thaut, 2005). Patterned sensory enhancement utilises musical components such as rhythm, melody, harmony and dynamics to provide temporal, spatial and force cues (Thaut, 2005), in order to drive functional movement exercises and ADL movement practice.

In identifying the purpose of music therapy in the rehabilitation of physical impairment, recent literature identifies that instrument playing encourages repetitive practice and engagement for stroke survivors with upper limb impairment (van Wijck, et al., 2011). Using rhythm and tone as the driving force to engage the paretic upper limb offers the individual an alternative way to modify their motor output. Therefore, when the individual engages in playing the instrument, the auditory feedback produced by the paretic upper limb may result in continued engagement. Evidence-based research suggests the potential of musical instrument playing in creating neural pathways in the brain by increasing the connectivity between the auditory and premotor cortices, also referred to as "audio-motor coupling" (Rodriguez-Fornells et al., 2012, p. 283).

Music therapy has a unique role in upper limb stroke rehabilitation through its ability to address multiple goals simultaneously. Not only does musical engagement promote repeated practice of the upper limb, it also gives the individual the opportunity to engage in non-verbal processing (Erkkilä et al., 2011). As recent literature identifies a global challenge faced by stroke survivors is the restoration of self (Raghavan, 2016), it can be inferred that by engaging the upper limb in instrument playing through improvisation may also foster non-verbal expression. That is; engaging the stroke survivor in instrument playing through free improvisation has the potential to provide a platform for functional recovery of the hand (addressing physical impairment) and non-verbal expression (addressing sense of self), simultaneously.

Music supported therapy in upper limb stroke rehabilitation

Music-supported therapy (MST) is an approach to upper limb stroke rehabilitation, distinct from music therapy. In MST, musical instruments are utilised for gross upper limb rehabilitation by health professionals other than music therapists. Through transmagnetic

stimulation and magnetic resonance imaging, music-supported therapy has been shown to induce profound neural changes in the contralateral sensorimotor cortex of survivors of chronic stroke (Rojo et al., 2011). It has been further postulated that increased connectivity between the auditory and premotor cortices, or "audio-motor coupling" (Rodriguez-Fornells et al., 2012, p. 283), may contribute to neuroplastic changes, resulting in improvements of motor function following music-supported therapy (Grau-Sánchez et al., 2013). Giving stroke survivors an alternative mechanism to modify their motor output by receiving immediate auditory feedback (i.e. music) allows them to potentially overcome sensory and proprioceptive deficits (Schneider, Schönle, Altenmüller, & Münte, 2007).

Functional electrical stimulation

Functional electrical stimulation (FES) is a well-established intervention for motor rehabilitation post stroke (Eraifej, Clark, France, Desando, & Moore, 2017). This intervention uses electrical currents to produce contractions in muscle fibres to assist the stroke survivor to engage repetitively in functional tasks, such as opening the hand to grasp an object (Kutlu, Freeman, Hallewell, Hughes & Laila, 2016). When used appropriately, it is suggested that electrical stimulation may also contribute to the promotion of neuroplasticity (Stinear & Hubbard, 2012). With particular reference to the upper limb, research has shown FES to be particularly beneficial for those with weakness in the affected hand (Cuesta-Gómez et al., 2017). There is strong evidence to suggest that FES treatment improves overall upper limb function in acute stroke (Howlett, Lannin & Ada, 2015).

Tablet technology in stroke rehabilitation

The main challenge for health care practitioners working with stroke survivors is to provide the appropriate and required amount of practice and feedback during the individual's rehabilitation (Wijck, Dodds, Cassidy, Alexander & McDonald, 2011). Tablet technology is an emerging avenue for upper limb stroke rehabilitation as it offers an accessible means for repetitive, intensive and task-specific training of the paretic upper limb, which has been shown to influence neuroplastic changes in the brain (Hubbard et al., 2009). This interactive avenue for rehabilitation may provide a less labour-intensive option than conventional treatment (Saposnik, 2014). As tablet technology becomes more accessible, the use of tablet technology in rehabilitation may prove to be a viable option for stroke survivors to independently maintain task-specific upper limb retraining post discharge.

The need for research

Drawing upon the individual benefits of FES, music therapy, and tablet technology for upper limb stroke rehabilitation identified within the literature, this case study sought to examine the effect of combining these three approaches through the FES+*ThumbJam* music therapy protocol. The theoretical framework informing this protocol was based on the benefits of non-verbal emotional expression (Galińska, 2015) and audio-motor coupling (Grau-Sánchez et al., 2013; Rodriguez-Fornells et al., 2012).

Previous research suggests that stroke survivors referred to music therapy for upper limb rehabilitation must have some level of functional activity in order to participate in instrument playing (Scholz et al., 2016; Chouhan & Kumar, 2012; Raglio et al., 2017; Thaut, Hoemberg, Hurt, & Kenyon, 1998;

Yakupov, Nalbat, Semenova, & Tlegenova, 2017). Therefore, these studies typically exclude stroke survivors with limited to no functional movement in the paretic upper limb. As neural plasticity is influenced by repetitive task practice, it is important to find a way in which to include stroke survivors with limited to no movement. At present, there does not seem to be any studies combining FES with a music therapy intervention for the purpose of upper limb stroke rehabilitation. The unique approach of combining FES with an iPad-based instrument promotes the opportunity to engage stroke survivors, with little or no function, in upper limb rehabilitation through music making.

Case Description

Snave, a 74-year-old female, was initially admitted to an acute hospital following a left pontine stroke. Snave was then transferred to a rehabilitation hospital within a week (6 days) following stroke onset. On admission to the rehabilitation hospital, Snave presented with right-sided hemiparesis including her lower limb, upper limb and lower face, resulting in difficulty with independent movement and speech. No cognitive impairments had been identified on admission. Soon after admission it became known that Snave was a retired pianist and Professor of Music.

On arrival to the hospital, Snave required a hoist for transfers as well as maximal assistance for personal care, including ADLs. Though she had no hand function in her paretic right upper limb, flickers of activity were observed in her finger flexors. Sensation and proprioception of the paretic upper limb were intact. Snave also had a pre-morbid history of right wrist pain, which was aggravated by instrument playing prior to the stroke. She had previously managed such pain with a resting splint and sling.

In the rehabilitation setting, the treating team often encourage the patient and their family to collaboratively engage in goal setting. The process of collaborative goal setting ensures that the purpose of different activities and therapies are made explicit to the patient and the treating team (Wade, 2009). Literature suggests that collaborative goal setting has a multitude of benefits, including motivation for achievement, co-ordination of engagement in prescribed therapy, and identification of all necessary goals (Wade, 2009). As with the case of Snave, her collaborative goals included: the ability to independently eat an apple (short-term goal), and play the piano again (long-term goal).

Snave's primary referral to music therapy was in regard to her difficulties in verbal communication due to hemiparesis to the lower mouth. Snave's initial music therapy treatment plan was centred on therapeutic techniques to strengthen the mouth muscles to enhance clarity of speech. During these sessions, Snave engaged in familiar song singing, musical discussion and analysis. The music therapist played live music as selected by Snave, including popular music and baroque flute music. This was to encourage Snave to not only engage in singing, but to also draw upon her skills as a Professor of Music. This further encouraged Snave to exercise the mouth muscles by analysing and discussing music in a context similar to her life prior to stroke onset.

It can often be difficult for the individual to control and/or verbally articulate their feelings associated with the resultant impairment/s of a stroke (Hart & Cicerone, 2018). For some, this may be as a result of communication or cognitive impairments, disrupting the pathways required to verbalise and/or organise thought patterns (Sudin et al., 2017). For others, this may be a result of the lack of

insight or reluctance to accept their resultant impairment/s (Bruno et al., 2017). As Snave was a professional pianist with significant weakness in her upper limb, it seemed important to give her an appropriate outlet to work through this. When the goals for music therapy started to focus more on the rehabilitation of the upper limb, based on Snave's preference, the music therapist encouraged and supported Snave to engage in concurrent free musical improvisation as a means of non-verbal expression.

It is important to acknowledge that written (signed) consent has been obtained for the purpose of research and the write up of this clinical case report. A pseudonym ("Snave") has been used to ensure de-identification of the patient.

Method

This clinical case report was conducted at a 37-bed rehabilitation hospital in metropolitan Sydney, Australia, where music therapy is available one day a week. Referrals to music therapy are made through a standardised referral book and screened by the Stroke and Neurological Coordinator to identify priority patients and their relevance for group or individual therapy. Music therapy interventions are based on the individualised patient goals of physical rehabilitation, cognitive rehabilitation, speech and communication rehabilitation and psychological support.

As part of the hospital treatment plan, Snave engaged in occupational therapy and physiotherapy for the upper limb; receiving myriad interventions for strengthening and functional retraining. During the second and third week of admission, the OT provided standard electrical stimulation, via *Verity Neurotrac*, to Snave's wrist and finger extensors (50Hz, 200µ intensity from; 30secs on/5secs off; 1-2x daily up to 60 minutes). Whilst the machine was active, Snave engaged in a functional task (opening her hand to grasp a cup). This method was identified as FES. During FES, the muscle/s are electrically stimulated at a specific moment, when the patient is to engage in a specific activity (de Kroon, Lee, IJzerman & Lankhorst, 2002). The purpose of FES is to improve the performance of a specific activity. The machine was programmed to have 'on' and 'off' periods of electrical stimulation; the 'on' periods of electrical stimulation delivered a continuous contraction to the targeted muscles, while the 'off' periods ceased electrical stimulation.

Being aware of Snave's musical background when observing her engage in FES, the music therapist proposed that a musical task could potentially be more motivating. As Snave only had flickers of activity in the right finger flexors, the music therapist suggested an iPad-based instrument using the application *ThumbJam*. This application is touch sensitive and can be programmed to the individual's preference for instrument sound and scale. Prior to the commencement of this intervention (henceforth "FES+*ThumbJam*"), incorporating musical instrument playing with FES had not been previously suggested.

In week 4 of Snave's admission, the FES+*ThumbJam* intervention was trialled in a collaborative music therapy and occupational therapy session. The OT set up the *Verity Neurotrac* electrical stimulation device on the wrist extensor muscles prior to the session. A flute sound was programmed into the *ThumbJam* application as flute had been used by the music therapist in previous sessions and also had a more obvious sustain in comparison to other *ThumbJam* instrument options. Snave selected a scale to be programmed, and then

engaged in exploring the instrument. The music therapist provided wrist support to encourage Snave to actively raise her wrist during electrical stimulation of wrist extension, and to avoid any compensatory shoulder movement that could provoke shoulder pain.

Snave was encouraged to engage in playing the iPad instrument (*ThumbJam*) during the 'on' periods of electrical stimulation. The target movement of the initial session was wrist extension. As electrical stimulation initiated the movement of wrist extension, Snave was then directed to engage in finger movement (improvisation) on *ThumbJam* during 'on' periods of electrical stimulation. Even though Snave had limited strength and activity in her fingers, she was able to produce sound on the iPad instrument, as it was touch-sensitive. It was for this quality that the iPad instrument was used over standard acoustic instruments. The iPad instrument was also able to pick up even the subtlest of movements, offering both auditory and visual feedback to Snave.

For the majority of this initial session, Snave actively engaged in wrist extension with some finger movement when creating music with *ThumbJam*. Snave verbally reflected enjoyment in creating music with FES+*ThumbJam* and noted that the pace of the session felt faster than usual. On completion of this initial session, Snave requested further ongoing sessions. These sessions were weekly, due to the availability of the music therapy program at the facility.

Week 5 of Snave's admission replicated the trialled FES+*ThumbJam* intervention of week 4. In week 6, Snave engaged in directed improvisation, focusing on individual finger use and by week 7, she no longer required wrist support from the music therapist. In week 8, the music therapist encouraged Snave to play a known song ("Twinkle Twinkle") requiring a span of 6 notes on the iPad. After successfully executing this on the iPad with FES, Snave was then able to transfer this skill to a standard touch-sensitive keyboard (with FES). The music therapist accompanied Snave on the keyboard both to encourage increased engagement in the intervention and provide non-verbal support. At week 9, Snave was able to engage in independent keyboard practice without the FES. A timeline of the protocol can be found below in Figure 1.

The implementation of the FES+*ThumbJam* intervention was initially centred on physical rehabilitation goals due to the referral and pre-determined 'on' and 'off' periods of electrical stimulation. As moments of improvisation were implemented throughout the 'on' periods of electrical stimulation, Snave was encouraged to explore the instrument as much as she could, through free improvisation. It was after these moments, that Snave would verbally reflect upon her changes in motor movement as well as her feelings associated with these new changes. Therefore, non-verbal expression through free improvisation playing seemed to be a by-product of the intervention.

Figure 1. *The FES+ThumbJam protocol*

WEEK 2-3	WEEK 4	WEEK 5	WEEK 6	WEEK 7	WEEK 8	WEEK 9
FES Wrist/finger extensors; 30-60 mins 1-2x per weekday	FES+*ThumbJam* Selected scale; 1 x 45 -minute session with Registered Music Therapist (RMT)	FES+*ThumbJam* Wrist support + free improvisation; 1 x 45-minute session with RMT	FES+*ThumbJam* Wrist support + directed improvisation (finger focus); 1 x 45-minute session with RMT	FES+*ThumbJam* Improvisation (NO WRIST SUPPORT); 1 x 45-minute session with RMT	FES & Keyboard 1 x 45-minute session with RMT	Keyboard Independent practice with keyboard at bedside

Table 1. *Ongoing upper limb assessment*

Right Upper Limb	Initial Assessment	Week 8	Discharge Week 10	7- Month Follow Up
9 Hole Peg Test	Unable	1 min, 19 sec	54.08 sec	43.57 sec
Pinch Dynamometer (kg/F)	Unable	2	3.66	4
Grip Dynamometer (kg/F)	Unable	6.3	4.16 (lower due to shoulder pain)	8.33
Functional Use	Nil	Could drink from a cup independently	Using utensils for mealtimes	Can tie shoe laces
Musical Function	Nil	Could play scales on the keyboard with the FES once set up by therapists	Keyboard – independent scales practice	Bach on the piano

Results

As per the standard protocol at the hospital, data from the *9 Hole Peg Test* (9HPT) and tests of dynamometry were collected to determine Snave's progress throughout her admission. The results of these standard tests, functional use and musical function over Snave's admission period (initial assessment, at 8 weeks and at 10 weeks) and 7 months follow up are indicated above in Table 1.

When asked about her experience of the FES+*ThumbJam* intervention, Snave particularly highlighted the motivational aspects of this mode of therapy. Table 2 lists three quotes from Snave at the 7-month follow up.

Table 2. *Snave's feedback*

7-month follow up feedback
• "Once the FES [and iPad-instrument *ThumbJam*] started, I had an impetus to get things started."
• "I got some feedback… the sound I made and the feeling that I could move in a small increment was better than nothing and got better over time."
• "Getting the brain unstuck and getting it to remember what it used to do."

Discussion

The outcomes of this retrospective clinical case report demonstrate that FES+*ThumbJam*, a novel therapeutic intervention, may have had a positive impact on the rehabilitation of the paretic upper limb in this stroke survivor. This potential positive impact was predominantly identified through qualitative feedback and quantitative progression. As musical function was a long-term goal for Snave, this was an important area to be trained and examined during admission and at follow up. Initially, Snave engaged in music therapy for upper limb rehabilitation using FES and the touch sensitive iPad instrument. Her progression to using the keyboard with FES exemplifies her improvement in strength. Her progression to keyboard only (without FES) and ability to resume playing a known piece bilaterally at 7 months post discharge indicates her improvement in co-ordination and strength. Though this was further exemplified by her improvement in the 9HPT and the tests of dynamometry at the 7-month follow up, there is insufficient data to conclude that the FES+*ThumbJam* intervention made a quantifiable contribution to Snave's progress. However, this clinical case report does suggest the feasibility of FES+*ThumbJam* in upper limb stroke rehabilitation. Qualitative data further suggests that FES+*ThumbJam* was motivating for Snave.

Snave did not have her own iPad during her inpatient admission and was unable to practice between sessions. However, when Snave progressed to using the standard keyboard, she was able to access a standard keyboard for daily practice. As this case study is written in retrospect, the number of keyboard practice sessions between music therapy sessions is absent. Upon discharge, Snave reflected practicing piano up to 3 hours a day, consisting of technical work (e.g. scale practice) and repertoire (e.g. Bach's Prelude in C).

The music therapist's directions encouraged Snave to focus on a specific goal each session (e.g. free improvisation, finger

focus or song focus), determined by her progress. This aspect of the intervention allowed for task-specific training, which has been shown to generate neuroplastic changes in the brain (Hubbard, Parsons, Neilson, & Carey, 2009). Even though FES+*ThumbJam* met the essential criteria to promote motor re-learning and neural plasticity, we cannot conclude that any significant functional improvement resulted from the intervention (due to its limited application). However, there may have been potential for the establishment of new neural pathways through audio-motor coupling (Grau-Sánchez et al., 2013) and the fact that the intervention was repetitive in nature and allowed task progression with a high intensity of practice. Incorporating both visual and auditory feedback to subtle movements also made this intervention sensory rich. And, as the task related to her long-term goal, Snave remained engaged throughout.

Engaging in free improvisation gave Snave the opportunity to explore sound in the moment, encouraging non-verbal expression. Further to this, and as indicated in Table 2, Snave reported feeling motivated by the auditory feedback of the music she created using *ThumbJam*. Further engaging in playing a known song ("Twinkle Twinkle") gave Snave a framework with a set outcome which was continued post discharge (as she relearned Bach's Prelude in C). The fact that Snave felt motivated to engage in self-directed practice post discharge was significant, resulting in the set outcome of re-learning a piece of music from her past.

It is important to acknowledge the fact that Snave's background as a professional pianist could have been a contributing factor to her progress. Furthermore, as this is a retrospective clinical case report, care should be taken in generalising the outcomes of this case to other stroke survivors, including those who are also musicians. As no measures were taken immediately pre and immediately post each music therapy session, there is no evidence to support the notion that a single session of music therapy per week, had an isolated impact on Snave's upper limb functioning.

It is also worth noting that for other musician stroke survivors, this intervention may be too confronting or even frustrating to engage in due to their prior experience with playing music. Even though the outcome of this clinical case report is certainly related to Snave's musical background and intrinsic motivation, the authors have since trialled this intervention in non-musicians with some success. With set up assistance from therapists, the FES+*ThumbJam* protocol could allow stroke survivors, with a very weak upper limb, the opportunity to engage in continued self-directed practice of the paretic upper limb. Therefore, the primary contribution of this clinical case to the current literature is to include stroke survivors with limited function of their upper limb in musical engagement. The combination of FES and music therapy interventions supported the functional rehabilitation of extremely limited upper limb movement for this patient. This seems contrary to existing literature stating that traditional music therapy for upper limb rehabilitation requires an initially greater level of functional movement.

Future Research

Snave reported an increase in motivation for upper limb rehabilitation due to the musical nature of the intervention. The resultant auditory feedback encouraged the repetitive practice of functional upper limb movement patterns (La Gasse & Thaut, 2012). Audio-motor coupling may have had the

potential to influence neuroplastic changes (Grau-Sánchez et al., 2013) through the alternative mechanism to modify Snave's upper limb movement (Schneider et al., 2007) provided by the FES+*ThumbJam* intervention. From initially being unable to complete the assessment tasks at all, Snave demonstrated improvements in all areas of assessment at discharge, which had continued to improve at 7 months post discharge.

As this was a single retrospective clinical case report, there is not enough evidence to suggest a strong case for the routine inclusion of this music therapy protocol in upper limb rehabilitation. Further research is required to determine the effectiveness of this intervention on quantitative aspects of upper limb stroke rehabilitation, as well as to examine more specific qualitative aspects on the individual (for example; motivation and wellbeing).

Future research could examine the efficacy of the FES+*ThumbJam* intervention, specifically its influence on the overall recovery rate of upper limb function for stroke survivors, in comparison to standard treatments alone. In comparing the addition of FES+*ThumbJam* to standard treatment versus standard treatment alone, there is potential to see an impact on both qualitative and quantitative parameters. Using specific music therapy interventions with individualised task progression according to the upper limb function of the individual may provide a more consistent and structured approach to music therapy in upper limb stroke rehabilitation. To extend the FES+*ThumbJam* protocol, 'free improvisation', 'directed improvisation' and 'song learning' could be incorporated into each session, with task progression of each area dictated by a decision tree. When assessing the upper limb, measures of function and standardised manual muscle tests should also be conducted to measure outcomes. In order to establish the effectiveness of this intervention in upper limb stroke rehabilitation, the implementation of a clinical trial is recommended.

Finally, tablet technology and applications such as *ThumbJam* provide a low-cost option for upper limb retraining that stroke survivors can continue to use at home. Music therapists can instruct stroke survivors on appropriate ways to engage with the application as they are nearing discharge. This may lead to more independent task practice and repetition, and thus greater potential for audio-motor coupling, neuroplastic changes, increase in hand function and non-verbal emotional expression.

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