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## **An exploration of** physiotherapists experiences of robotic therapy **in** upper limb rehabilitation **within a stroke rehabilitation centre**

### **Abstract**

**Purpose:** Strokes are the world's leading cause of adult disability, with movement impairment being more common in the upper limb (UL). Robotic therapy (RT) is identified as an effective adjunct **to promote** movement but **with** limited effect on functional capabilities. There is currently limited research in user experience **of RT**, specifically that of physiotherapists. This study sought to explore physiotherapists experience of using RT in rehabilitation of the UL, **within a stroke rehabilitation centre in the north of England**.

**Method:** Physiotherapists (n=6) shared their experiences **of working with the InMotion2 robot** through semi-structured interviews. Thematic analysis was employed to interpret data, identify emergent themes and interdependent relationships between them.

**Findings:** Five interdependent themes were identified focused around individualised care, influenced by evidence for practice, human relationships, skill mix, and resources and resource management. All physiotherapists valued the use of RT as an adjunct to conventional therapy, although barriers to successful implementation seemed to dominate the views of some.

**Conclusions:** RT was perceived positively by physiotherapists, regarded as an adjunct to conventional therapy. A framework to summarise the relationships of participants' views and experiences is proposed in an attempt to understand the influences on the clinical use of RT.

## **Introduction**

Stroke is a leading cause of adult disability, with approximately 152,000 reported cases each year in the UK [1], increased dependency following stroke costing the National Health Service (NHS) £1.8 billion each year and treatment adding a further £2.8 billion [2]. Motor impairment affects about 80% of people following stroke [3] a substantial proportion of whom are left with permanent disability [4]. Often less time is devoted to upper limb rehabilitation which combined with decreased spontaneous recovery [5] contributes to limited recovery of function for the upper limb [3, 6].

Effective approaches to improve upper limb motor function include high-intensity, repetitive, task-specific, goal-directed rehabilitation [7]. Intensive, repetitive exercise promotes cortical reorganisation for re-establishment of movement [3] with several hundred repetitions required daily to make progress [8]. This usually requires one-to-one therapeutic interactions for an extended period of time [1]. Self-help exercises are promoted but it is estimated that only 31% of patients perform these [9], the level of impairment obviously being a limiting factor [10].

The proliferation and potential of technology has been a dominant feature of 21st Century society in general, including healthcare and rehabilitation. This article reports on research carried out as part of a pre-registration MSc Physiotherapy award, to explore physiotherapists experience of using Robot Therapy (RT) in rehabilitation of the upper limb following stroke.

Robot Therapy (RT) can be defined as the application of electronic computerised control systems to mechanical devices designed to perform human functions [11]. There are two general classifications of rehabilitation robots currently designed for stroke rehabilitation. End-effector systems interact with the patient using a single distal attachment, whilst exoskeletons encapsulate the arm and seek to replicate the human skeleton through various links and joints [12]. Exoskeletons allow full, spatial, multi-joint function and provide contact along the limb, much like a therapist might do to facilitate movement [13]. There is insufficient evidence to draw firm conclusions in relation to exoskeleton devices on upper limb function [14], but end-effector systems have been shown to hold potential, especially with more chronic strokes. A recent Cochrane Review [15] has suggested improvement in activities of daily living following electromechanical and robot-assisted arm and hand training after stroke. However, evidence was reported as 'low to very low' in terms of quality and the authors suggested that repetitions were perhaps improved with the technology and could therefore be used as an adjunct to conventional therapies.

The robotic device with the most clinical testing is the MIT-MANUS (commercially available as InMotion2) [1]. With this device the patient's arm is placed in an orthotic support attached to the robot arm, in order to provide assistance in the horizontal plane through interaction with a computer screen showing 2D games [16]. Low friction/impedance allows smooth and extremely compliant movements, (ibid) and the patient receives dual-feedback from the force of the robot and visual from the screen [17]. The InMotion2 robot is complemented by the InMotion3, which is designed for the wrist. Interactive Motion Technologies (IMT) states that the two can be used in conjunction or as stand-alone treatments [18].

The principle behind RT is in promoting intense repetitive training [19] with little to no supervision [11, 20]. The devices do not fatigue [20] and can therefore support an intensive programme, of greater repetitions and longer treatment sessions, often within a group environment [17, 21]. However, Barnes et al. [22] argues robotic devices being unable to take into account physiological factors such as fatigue. The active-assisted protocol may also raise concerns; patients may opt to wait until the robot performs the task for them [21] rendering movement passive and lessening stimulus for adaptation. Functional relevance has also been questioned [19].

It must be stressed that RT is not designed to replace physiotherapists, but to improve biomechanical factors to facilitate repetitive movement [23]. Not all patients may benefit from RT, for example the InMotion2 focuses on gross movements, particularly of the shoulder and elbow [17].

Overall, the evidence is quite positive in supporting the efficacy of RT in promoting motor activity, reducing impairment and disability [24, 25, 26]. Although there is evidence to suggest that RT is enjoyed and well-tolerated by service users [27] there is an identified need for research based on the experiences of the rehabilitation professionals in working with RT [16]. Thus this research sought to explore physiotherapists views and experiences using robot therapy in the rehabilitation of the upper limb following stroke.

## **Methods**

A phenomenological approach was undertaken through individual semi-structured interviews with six physiotherapists working with robotics at a local stroke rehabilitation facility. Ethical approval was gained from the University Faculty Ethics Committee, along with Healthcare Trust approval.

The sample was accessed via the clinical specialist physiotherapist for the stroke rehabilitation service at a North of England Stroke Rehabilitation Centre. Purposive sampling was then undertaken to ensure that volunteer participants, registered physiotherapists currently employed within the service had experience of working with the InMotion2 robot [28].

**INSERT FIGURE 1 HERE**

The interviews were undertaken by AS within a quiet room at the Rehabilitation Centre. Individual interviews were organised on separate days taking place over a two-week period during August 2014 to ensure minimal disruption to the physiotherapy service and support continuous design [29]. Duration of each interview was approximately one hour and although participant confidentiality was respected it would be naive to assume that participation would not have been discussed among the workforce [30]. Each participant was assigned an identity code and pseudonym prior to interview in the interests of confidentiality [31].

Transcription was completed following each interview, seeking a continuous design in the exploration of emerging topics in subsequent interviews [29]. Member-checking was

undertaken whereby participants were emailed a copy of their interview transcript to ensure accuracy [32] and satisfaction with their responses [33]. All six participants responded and verified their transcripts.

Emergent themes were identified through inductive analysis of transcripts [34, 35]. Investigator triangulation moderation [JS], was undertaken to compare and discuss themes in an attempt to control bias [36] and enable tentative model construction [37] that seeks to explain physiotherapists views and experiences of RT.

## **Findings and discussion**

Table 1 provides an overview of relevant participant characteristics in to provide context for the findings.

**INSERT TABLE 1 HERE**

Overall, participants were positive towards the use of RT as an adjunct to therapy rather than a primary intervention. There was a clear value placed on individualised person centred rehabilitation with, unsurprisingly, the predominant barrier to the use of RT being largely related to resources. Figure 1 presents the emergent themes of the research presented in the form of nested groups which best represents the complex nature of person centred RT in an attempt to understand and explain the interdependent nature of emergent themes and how they may interact [38] in influencing physiotherapists decision-making.

**INSERT FIGURE 2 HERE**

### ***Individualised care***

The focus of RT for all of the study participants was in the support of individualised, person-centred care. The InMotion2 robot was primarily designed as a tool to improve rehabilitation efficiency [39] and augment a physiotherapist's skills [40] rather than for use in isolation. The Intercollegiate Stroke Working Party [41] recommend RT as an adjunct to conventional therapy, a view supported by the study.

*“Getting more therapy to patients ...as an adjunct to physiotherapy treatment”* (Barry)

*“It has to be an extra to therapy ... I never saw it as a main avenue of treatment”*

(Penny)

The InMotion2 improves biomechanical factors such as ROM [42], improvements being specific to the motions performed, as supported by Hebbian theory [43].

*“That’s the whole point, isn’t it ... you use the robot and with that recovery would try to influence functional tasks”.* (Ruth)

Although all understood the purpose of the InMotion2 to provide an increased number of repetitions in an attempt to promote plasticity, only one participant (Ruth) made an explicit



link to function. Others commented on this point but did not appear convinced, viewing a perceived lack of a functional link as a limitation of the robot.

*“While on the robot can achieve good movements ... not sure how much that carries over when not strapped to the robot” (James)*

*“[Functional Tasks] the robots lack in ... but make up for it in repetition” (Fiona)*

*“I’m not convinced it is practical ... arm strapped to a machine rather than producing a functional movement ... robot is a way of getting movement ... might give more ROM but if it doesn’t impact function then what’s the point?” (Dave)*

This is a common view in existing literature [19], although notable functional improvements were witnessed in the study, with contextual ‘riders’:

*“He was starting to write again, which he hadn’t done until he started on the robot” (Fiona)*

*“There were patients who did recover function ... but participated in other therapy modalities so I couldn’t say it was purely from the robot” (Penny)*

Obviously, it would be naive to accredit improvements solely to the robot, and the clinical setting being a stroke rehabilitation ward, there will be a broad range of factors influencing recovery. Although Penny was not convinced by RT, others were quite pragmatic in the perceived value of RT

*“The robot can achieve a lot more repetitions than we can” (Fiona)*

*“Provide something we could never do ... repetitions” (Ruth)*

Ruth suggested that the robot could provide something we ‘could never do’ in terms of repetitions, and thereby relieve stress on the therapists [1]. However, Lum et al. [44] suggested that robots could never replace humans from a perspective of clinical decision-making, which was recognised by the physiotherapists in this study, particularly with regard to assessment, reinforcing the opinion of RT as an adjunct to therapy.

Study participants also identified valuable additional effects of RT in relation to inattention and neglect.

*“(Cognitive Impairment) couldn’t follow what was going on, also lose concentration and focus ... it definitely did help with neglect and attention, ... (games) really did keep them engaged and focused” (Penny)*

The role of games in promoting movement and motivation is stated at the IMT website [18], but not commonly reported within the literature. The patient-centred focus of this study was often defined by resources, underpinned by cost within the NHS, perhaps making an outpatient setting a more appropriate setting for RT at the moment. It was felt that upper limb rehabilitation may be a greater priority for patients at that point, the vast majority of patients being motivated towards walking again at earlier stages of rehabilitation. A greater priority at a later stage could explain why evidence tends to place a greater emphasis for RT in a more chronic setting rather than acute [45].

### ***Evidence-based practice***

Not all study participants were familiar with current RT research. However a feature of engagement with evidence when presented with it, was a rigorous level of critical thinking in relation to implications for practice.

*“Whether or not that is sustainable actually outside of a study, within the NHS would be another matter ... modify what happens in a clinical trial onto the ward” (Penny)*

*“How many patients were in these studies? ... What were the outcome measures? ... the problem I have with outcome measures is they’re not always sensitive enough ... small gains that could be massive to them ... but the outcome measures aren’t sensitive enough to pick that up ... I would set out a program for them, 3-4 times a week for at least a month” (Ruth)*

It was evident that there was a commitment to the use of best evidence to support practice but also the recognition that research can often be limited in terms of day-to-day relevance [46]. Penny highlighted this, and questioned if intensity levels would be sustainable within the NHS, raising management of resources, and modification of intensity as a possible option. In addition Ruth held a strong opinion that many outcome measures used at clinical trials, generally, were not sensitive enough to detect change. This is another proposed advantage of robotics, in recording minimal changes [42]. However, as Barry stated:

*“The patients’ aim is not to get a higher score, it’s being able to do something functionally.”*

Measures from the robot could therefore be valuable in measuring change, which in turn can influence patient motivation, but it is the goal of achieving functional tasks that dominates for patients. Patients can experience difficulty in understanding performance graphs produced by the robots, which could undermine the value to patients [27]. Fiona believed that it was a role of the therapist in relaying information to patient.

*“Need to add that human element for people that don’t relate to it as well ... may need to interpret the type of information that is on the screen.”*

### ***Human relationships; information and communication***

The motivational and physical benefits of independent exercise programmes are noted [27]. However, all of the physiotherapists agreed that some form of supervision was necessary whilst working with the robot:

*“You couldn’t just let the patients just do the robots on their own ... you have to be around to give encouragement but you don’t have to be hands on ... tailor the feedback to the patient”* (James)

*“I don’t think you can just leave a patient ... needs that human element of interaction ... checking from a fatigue point of view ... often they will need a physical prompt to stop them from using compensatory movement”* (Fiona)

*“You need to be there with your patient ... at all times when they are on the robot ... looking at their posture, concentration ... reminders about sitting upright ... safe in the chair”* (Penny)

Therapeutic relationships would appear to form the foundation for successful person-centred intervention. The issues raised - fatigue, compensation and positioning - may also be related to the stage of recovery but equally highlight implications for safety as well as efficacy of the intervention. Robots are unable to take into account factors related to quality of movement [22]. Supervision is vital to ensure that 'correct' movements are being performed, as improvements are specific to movements performed [25, 43]. However, on a positive note related to independent exercise, James provided an interesting view:

*“More ownership over therapy ... they feel like they’ve done more themselves because you’ve not got a therapist facilitating ... they feel like they’re working independently.”*

The physiotherapists raised a number of points related to supervision including professional body requirement for safe and effective practice [47]. Indicators for the level of supervision required may influence RT inclusion as part of rehabilitation, skill mix in service delivery, and working with multiple patients. Krebs and Hogan [48] explain that one of the factors that should be considered with regard to success of neuro-rehabilitation methods is the cost/benefit ratio, so that the required level [and therefore cost] of supervision may be an important factor in the uptake of RT.

Liddell et al. [49] suggests that acceptance of RT by the patient is vital. Within this study physiotherapists perceptions were that patients generally enjoyed RT, although there were some exceptions.

*“Patients like it because they can see how much they improve ... (lower score) they see that as quite frustrating ... it’s quite a novel thing, it’s always going to appear attractive” (James)*

*“Initially the novelty value, they loved it, after a couple of sessions they got very bored ... game became very difficult based on a no-win situation” (Barry)*

Continued engagement was perceived to be linked to tailored feedback. RT appeared interesting to patients but was, initially at least, often based on novelty value. Therefore, it may be important to account for initial novelty value before determining if patients will meaningfully accept RT and appreciate that RT may not be for everyone [17].

Interestingly Dijkers et al. [50] claimed that although therapists perceived RT was boring for patients, the patients themselves responded very positively. Obviously it is difficult to reflect another's opinion, but general research findings indicate that RT is enjoyable [27, 50], both motivating and satisfying [42], but at times frustrating [51]. This potential for frustration highlights the importance of supervision, and reinforces the notion of healthcare as being delivered by humans for humans [52].

### ***Skill mix***

Staff relationships and therefore skill-mix is paramount with regard to decision-making, and service delivery. Utilisation of different grades of staff was, predictably, appreciated in the delivery of safe, effective and also efficient rehabilitation. Physiotherapy assistants could supervise multiple patients, as long as a qualified physiotherapist performed an

initial assessment. This was regarded as an important factor to ensure appropriate treatment and the individualised approach.

'Technical' relationships (technical support) also appeared to have an impact on the therapy provided and ultimately the individualised element. Frequent reference to the importance of technical support was given, and the necessary training for the most effective use of RT with clear implications for continuing education and development of staff.

*"Someone who worked for the manufacturers came over to give us some training about the robot ... it needs maintenance ... on one occasion a mechanic was here for 20 minutes and solved the problem"* (Fiona)

*"When [physiotherapist from company] came from the US ... she came and showed us how to use them properly and it was fab"* (Ruth)

Brewer et al. [17] reported that staff needed appropriate training and the interdependence between the technical and human has been recognised when delegating tasks [53]. This also includes clinical members of staff giving support to therapy assistants who are providing RT in this study. The efficient use of resources, is a powerful influence on effective decision-making. Porter [54] suggests that an appropriate skill mix is required to provide effective care with best use of resources. A suggested benefit here is that it frees up higher-grade staff members' time [55], a proposed advantage of RT [2].

*"Qualified to do the bits they need to be doing, and your assistant can take two patients*

*off and do the robot ... (assistant) does the robots to free me up to do qualified sessions” (James)*

*“Patient-by-patient basis ... there should be a physio(therapy) assessment to lead into the treatment for an assistant to take over” (Fiona)*

*“Assistant would need to have basic training in normal movement” (Dave)*

A qualified physiotherapist should perform the initial assessment and review at various stages, as it is important for identifying patterns of movement to be performed [56]. The potential interdependence between evidence-base and skill-mix was recognised in highlighting the perceived benefits of and need for explicit guidelines:

*“Protocol to say this particular person may not do well on the robot ... start to get together some guidelines and protocols as to the type of patients that could be suitable for it” (Barry)*

*“If it showed positive results I’d try and follow those guidelines ... I think you need to pick your patients carefully” (Dave)*

Beddow [57] suggests that physiotherapy support workers are and can fulfil different responsibilities through protocol or guideline-driven care. RT could be suggested as an appropriate modality for this and with effective use supported by clinical guidelines. The current broad guideline for stroke therapy is for patients to receive 45 minutes rehabilitation, if they continue to benefit and are able to tolerate it [58]. However it was recognised:



*“45 minute session, some will be legs ... won't have 45 minutes solidly of arm” (James)*

*“We haven't got the staff to give everyone 45 minutes of therapy a day” (Ruth)*

This again highlights the influence of prioritisation and resource management. However, RT's role as an adjunct should also be remembered; the robot is not there to 'replace the physiotherapist' [23]. Care must remain individualised and assistants would have to be deemed capable of providing the therapy session.

### ***Resources & resource management***

Resources and resource management are a common factor influencing all aspects of RT. In terms of the equipment itself, physiotherapists did recognise the potential cost/benefit impact in terms of service efficiency, but the initial purchase price of the robot was seen as quite constraining.

It has already been suggested that effective skill mix enables best use of resources [54], and it was clear that this was a powerful influence among the physiotherapists. All six made explicit links to resources and time management.

*“Multiple patients doing therapy at the same time” (James)*

*“There's no reason why one person couldn't watch over four people” (Barry)*

*“It's fine to do it in a group, it doesn't need to be one to one ... as long as they're all getting enough attention” (Penny)*

Generally it is suggested that one member of staff may be sufficient to supervise a number of patients, which can reduce cost [1, 4]. However, it is important that everyone receive adequate attention required for a safe and effective intervention. Time management through use of a single supervisory therapist with a group of patients could potentially, increase therapy time and provide the opportunity for increased repetitions.

Krebs and Hogan [48] suggest that if a positive cost/benefit relationship was demonstrated, then RT could be promoted as a more mainstream intervention. Adapting to healthcare economies is the biggest challenge for robotics [59]. A reduction in cost or an increase in therapy time would, in theory, have a direct impact on the cost/benefit ratio.

*“It could be cost-effective if you had one person, and it didn’t necessarily have to be a physiotherapist ... weigh up cost of purchasing the robot, maintenance of the robot, storage of the robot” (Barry)*

*“If you can get the same improvements from standard interventions then I can’t see many trusts investing in robotics ... at the moment, I would imagine it is not hugely cost-effective” (Penny)*

*“If you’re looking at cost-effectiveness you can treat two patients at the same time with one physio(therapist)” (Ruth)*

Although it has been shown that standard interventions can provide similar results [43, 60], it appears to be the amount of therapy and repetitions as the dominant factor. The physiotherapists believed it would be hard to replicate the intensity of a lot of trials due to

the resources available. Although comparative standard interventions have been shown to provide similar results, it would also increase the cost per hour [61, 62].

Robotic therapy is believed to provide a reduction in cost per hour, as one therapist supports multiple patients [20, 21]. Barry also commented on maintenance and storage of the robot. Although cost analysis studies suggest a positive cost/benefit ratio [60, 62], only maintenance costs were accounted for and neither storage nor skill mix was commented on in those studies. This makes it difficult to gain an accurate measure of cost-effectiveness. The physiotherapists were concerned by the initial purchase cost, although Brewer et al [17] suggest that further technological development may lower costs and thereby ease transition into practice. This could be through improved design and an increased production rate. If design improvements did lead to the robots becoming smaller, this would reduce storage costs and allow for more patients in a group, as Barry stated:

*“Some of the problems we had in setting them up were to do with space; that was a big one.”*

### ***A call for a cultural shift?***

Steve Tolan suggests that physiotherapists could benefit from stepping further out of their comfort zone to engage with an increasing digital world [63]. It was interesting that only one physiotherapist in this study (overall) appeared to be developmental in their outlook being solution-orientated towards technology, rather than focus on the barriers to its use.

Only Ruth really embraced the technology as an integrated tool and provided solutions to the robot's capability, *"you would follow that up with functional task practice"*. Again, the InMotion2 is only one machine in the field of RT, and although development will continue, exoskeletons, that allow full spatial multi-joint function [13], may hold more promise.

Many of the therapists concerns involved perceived time constraints and the need for prioritisation of workloads. However, as already proposed, the robot may be able to increase therapy time (and movement repetition) to benefit patients and become a key part of mainstream stroke rehabilitation.

*"When I qualified it was very hands on ... still important ... need to look at the development because everything is improving with technology throughout life ... I think therapy and rehabilitation should not be left behind."* (Ruth)

This reflects the Department of Health's Digital Challenge, in which Jeremy Hunt states 'I want the NHS to be a world class showcase of what innovation can achieve' [64]. A mandate has also been set out for the NHS to make progress in the use of technology [65]. Therefore, cultural shift is required, and underway, to embrace technology. Interviews within this study were based around a single piece of equipment, with a small group of people making it difficult to comment on physiotherapists' uptake of technology in general. However, time resource is evident as an important influence.

*"I do feel I am quite negative about them ... I understand the theory, I wish we had more time to use them."* (Dave)

## **Conclusions**

Physiotherapists in this study were positive towards the use of RT as a person-centred adjunct to therapy although not entirely solution-orientated regarding the perceived limitations of RT as an intervention. This along with the challenges that surround resources and resource management, skill mix, and current lack of published guidelines formed the key barriers to truly embracing the technology. As the field of robotics develops, acceptance levels may rise, but physiotherapists, and rehabilitation in general, needs to be in a position to make best use of this by stepping out of established comfort zones to think differently in terms of potential benefits to the patients and a broader assessment of cost / benefit that includes initial cost, storage, maintenance, training and improved, efficient outcomes. Although predictable, it is clear from this study that resource management holds the biggest influence on practice and decision-making.

Any successful RT provision is dependent on human relationships, in providing safe, effective and efficient rehabilitation particularly in relation to provision of information, positioning, treatment setting parameters, and feedback whether technical or therapeutic. As with all healthcare interactions, therapeutic relationships are vitally important to provide the individualised focus with technical relationships particularly important for staff training, problem-solving and maintenance of equipment.

In terms of making sense of the existing evidence-base and the implications for practice, the development of clinical guidelines for RT would be seen as a logical and helpful development.

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## References

- [1] Huq R, Kan P, Goetschalckx R, Hébert D, Hoey J, Mihailidis A. A decision-theoretic approach in the design of an adaptive upper-limb stroke rehabilitation robot. International Conference held at International Conference on Rehabilitation Robotics [ICORR]; 2011 June 29-July 1; Zurich. Switzerland: IEEE; 2011. 8 p. Available from: <http://ieeexplore.ieee.org/xpls/icp.jsp?arnumber=5975418>
- [2] Jackson AE, Culmer PR, Levesley MC, Cozens JA, Makower SG, Bhakta BB. Effector force requirements to enable robotic systems to provide assisted exercise in people with upper limb impairment after stroke. International Conference held at International Conference on Rehabilitation Robotics [ICORR]; 2011 June 29-July 1; Zurich. Switzerland: IEEE; 2011. 6 p. Available from: <http://ieeexplore.ieee.org/xpls/icp.jsp?arnumber=5975391> .
- [3] Alankus G, Proffitt R, Kelleher C, Engsborg J. 2011. Stroke therapy through motion-based games: a case study. ACM Transactions on Accessible Computing [TACCESS] 4(1): 3. <http://dl.acm.org/citation.cfm?id=2039342> . Accessed 2016 July 05.
- [4] Kan P, Huq R, Hoey J, Goetschalckx R, Mihailidis A. 2011. The development of an adaptive upper-limb stroke rehabilitation robotic system. Journal of Neuroengineering and Rehabilitation 8(1): 1-18. <https://jneuroengrehab.biomedcentral.com/articles/10.1186/1743-0003-8-33> . Accessed 2016 July 05.
- [5] Sabini RC, Dijkers MP, Raghavan P. 2013. Stroke survivors talk while doing: Development of a therapeutic framework for continued rehabilitation of hand function post stroke. Journal of Hand Therapy 26 (2): 124-131. <http://www.ncbi.nlm.nih.gov/pubmed/23073514> . Accessed 2016 July 05.
- [6] Prange GB, Jannink MJ, Groothuis-Oudshoorn CG, Hermens HJ, IJzerman MJ. 2006. Systematic review of the effect of robot-aided therapy on recovery of the hemiparetic arm after stroke. Journal of Rehabilitation Research and Development 43(2): 171-184. <http://www.ncbi.nlm.nih.gov/pubmed/16847784> . Accessed 2016 July 05.
- [7] Backus D, Winchester P, Tefertiller C. 2010. Translating research into clinical practice: integrating robotics into neurorehabilitation for stroke survivors. Topics in Stroke Rehabilitation 17(5): 362-370. <http://www.ncbi.nlm.nih.gov/pubmed/21131261> . Accessed 2016 July 05.
- [8] Selzer M. Textbook of Neural Repair and Rehabilitation. Cambridge: Cambridge University Press; 2006. In Alankus G, Proffitt R, Kelleher C, Engsborg J. 2011. Stroke therapy through motion-based games: a case study. ACM Transactions on Accessible Computing [TACCESS] 4(1): 3. <http://dl.acm.org/citation.cfm?id=2039342> . Accessed 2016 July 05.

- [9] Shaughnessy M, Resnick BM, Macko RF. 2006. Testing a Model of Post-Stroke Exercise Behavior. *Rehabilitation Nursing* 31(1), p 15-21. In Alankus G, Proffitt R, Kelleher C, Engsborg J. 2011. Stroke therapy through motion-based games: a case study. *ACM Transactions on Accessible Computing [TACCESS]* 4(1): 3. <http://dl.acm.org/citation.cfm?id=2039342> . Accessed 2016 July 05.
- [10] Finley MA, Fasoli SE, Dipietro L, Ohlhoff J, MacClellan L, Meister C, Whittall J, Macko R, Bever CT Jr, Krebs HI, Hogan N. 2005. Short-duration robotic therapy in stroke patients with severe upper-limb motor impairment. *Journal of Rehabilitation Research & Development* 42(5): 683-692. <http://www.ncbi.nlm.nih.gov/pubmed/16586194> . Accessed 2016 July 06.
- [11] Kwakkel G, Kollen BJ, Krebs HI. 2008. Effects of robot-assisted therapy on upper limb recovery after stroke: a systematic review. *Neurorehabilitation and Neural Repair* 22(2): 111-121. <http://www.ncbi.nlm.nih.gov/pubmed/17876068> . Accessed 2016 July 06.
- [12] Pignolo L. 2009. Robotics in neuro-rehabilitation. *Journal of Rehabilitation Medicine* 41(12): 955-960. <http://www.ncbi.nlm.nih.gov/pubmed/19841823> . Accessed 2016 July 06.
- [13] Frisoli A, Procopio C, Chisari C, Creatini I, Bonfiglio L, Bergamasco M, Rossi B, Carboncini MC. 2012. Positive effects of robotic exoskeleton training of upper limb reaching movements after stroke. *Journal of Neuroengineering and Rehabilitation* 9(1): 36. <https://jneuroengrehab.biomedcentral.com/articles/10.1186/1743-0003-9-36> . Accessed 2016 July 06.
- [14] Chang WH, Kim YH. 2013. Robot-assisted Therapy in Stroke Rehabilitation. *Journal of Stroke* 15(3): 174-181. <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3859002/> . Accessed 2016 July 06.
- [15] Mehrholz J, Pohl M, Platz T, Kugler J, Elsner B. 2015. Electromechanical and robot-assisted arm training for improving activities of daily living, arm function, and arm muscle strength after stroke, *Cochrane Database of Systematic Reviews*, 11. [http://www.cochrane.org/CD006876/STROKE\\_electromechanical-assisted-training-improving-arm-function-and-disability-after-stroke](http://www.cochrane.org/CD006876/STROKE_electromechanical-assisted-training-improving-arm-function-and-disability-after-stroke) . Accessed 2016 July 06.
- [16] Mazzoleni S, Turchetti G, Palla I, Posteraro F, Dario P. 2014. Acceptability of robotic technology in neuro-rehabilitation: preliminary results on chronic stroke patients. *Computer Methods and Programs in Biomedicine* 116(2): 116-122. <http://www.sciencedirect.com/science/article/pii/S0169260713004070> . Accessed 2016 July 06.



- [17] Brewer BR, McDowell SK, Worthen-Chaudhari LC. 2007. Poststroke upper extremity rehabilitation: a review of robotic systems and clinical results. *Topics in Stroke Rehabilitation* 14(6), 22-44. <http://www.ncbi.nlm.nih.gov/pubmed/18174114> . Accessed 2016 July 06.
- [18] IMT. 2014. Upper Extremity Rehabilitation. Available: <http://interactive-motion.com/healthcarereform/upper-extremity-rehabilitation/inmotion-wrist/> . Last Accessed 2016 July 06.
- [19] Scott SH, Dukelow SP. 2011. Potential of robots as next-generation technology for clinical assessment of neurological disorders and upper-limb therapy. *Journal of Rehabilitation Research & Development* 48(4): 335-353. <http://www.ncbi.nlm.nih.gov/pubmed/21674387> . Accessed 2016 July 06.
- [20] Harvey RL. 2009. Improving poststroke recovery: neuroplasticity and task-oriented training. *Current Treatment Options in Cardiovascular Medicine* 11(3): 251-259. <http://www.ncbi.nlm.nih.gov/pubmed/19433020> . Accessed 2016 July 06.
- [21] Norouzi-Gheidari N, Archambault PS, Fung J. 2012. Effects of robot-assisted therapy on stroke rehabilitation in upper limbs: systematic review and meta-analysis of the literature. *Journal of Rehabilitation Research & Development* 49(4). 479-496. <http://www.ncbi.nlm.nih.gov/pubmed/22773253> . Accessed 2016 July 06.
- [22] Barnes MP, Dobkin BH, Bogousslavsky J. 2005. *Recovery After Stroke*. Cambridge: Cambridge University Press. In Kan P, Huq R, Hoey J, Goetschalckx R, Mihailidis A. 2011. The development of an adaptive upper-limb stroke rehabilitation robotic system. *Journal of Neuroengineering and Rehabilitation* 8(1): 1-18. <https://jneuroengrehab.biomedcentral.com/articles/10.1186/1743-0003-8-33> . Accessed 2016 July 06.
- [23] Loureiro RC, Harwin WS, Nagai K, Johnson M. 2011. Advances in upper limb stroke rehabilitation: a technology push. *Medical & Biological Engineering & Computing*, 49(10): 1103-1118. <http://www.ncbi.nlm.nih.gov/pubmed/21773806> . Accessed 2016 July 18.
- [24] Rabadi MH, Galgano M, Lynch D, Akerman M, Lesser M, Volpe BT. 2008. A pilot study of activity-based therapy in the arm motor recovery post stroke: a randomized controlled trial. *Clinical Rehabilitation*, 22(12): 1071-1082. <http://www.ncbi.nlm.nih.gov/pubmed/19052246> . Accessed 2016 July 18.
- [25] Daly JJ, Hogan N, Perepezko EM, Krebs HI, Rogers JM, Goyal KS, Dohring ME, Fredrickson E, Nethery J, Ruff RL. 2005. Response to upper-limb robotics and functional neuromuscular stimulation following stroke. *Journal of Rehabilitation Research and Development*, 42(6): 723-736. <http://www.ncbi.nlm.nih.gov/pubmed/16680610> . Accessed 2016 July 18.

- [26] Volpe BT, Krebs HI, Hogan N, Edelstein L, Diels C, Aisen M. 2000. A novel approach to stroke rehabilitation Robot-aided sensorimotor stimulation. *Neurology*, 54(10): 1938-1944. <http://www.ncbi.nlm.nih.gov/pubmed/10822433> . Accessed 2016 July 18.
- [27] Hughes AM, Burridge J, Freeman CT, Donovan-Hall M, Chappell PH, Lewin PL, Rogers E, Dibb B. 2011. Stroke participants' perceptions of robotic and electrical stimulation therapy: a new approach. *Disability & Rehabilitation: Assistive Technology*, 6(2): 130-138. <http://www.ncbi.nlm.nih.gov/pubmed/20698789> . Accessed 2016 July 18.
- [28] Macnee CL, McCabe S. 2008. *Understanding Nursing Research: Using Research in Evidence-Based Practice*. London: Lippincott Williams & Wilkins. p 122.
- [29] Rubin HJ, Rubin IS. [2012]. *Qualitative Interviewing: The Art of Hearing Data*. London: Sage Publications. p 42.
- [30] Wethal UB. 2011. *Strategies of Avoidance-Value Chain Reactions in the Durban Clothing Industry: MA Thesis, University of Oslo*. In Furseth I, Everett EL. 2013. *Doing Your Master's Dissertation: From Start to Finish*. London: Sage. p 115.
- [31] Pitney W, Parker J. 2009. *Qualitative research in physical activity and the health professions*. West Yorkshire: Human Kinetics. p 74.
- [32] Harper M, Cole P. 2012. Member Checking: Can benefits be gained similar to group therapy. *The Qualitative Report*, 17(2): p 510-517.
- [33] Kvale S. 2006. Dominance through interviews and dialogues. *Qualitative inquiry*, 12(3), 480-500. In Costley C, Elliott GC, Gibbs P. 2010. *Doing Work Based Research: Approaches to Enquiry for Insider-Researchers*. London: Sage. p 41.
- [34] Hsieh HF, Shannon SE. 2005. Three approaches to qualitative content analysis. *Qualitative Health Research*, 15(9): 1277-1288. <http://qhr.sagepub.com/content/15/9/1277.short?rss=1&ssource=mfc> . Accessed 2016 July 18.
- [35] Vaismoradi M, Turunen H, Bondas T. 2013. Content analysis and thematic analysis: Implications for conducting a qualitative descriptive study. *Nursing & Health Sciences*, 15(3): 398-405. <http://onlinelibrary.wiley.com/doi/10.1111/nhs.12048/abstract> . Accessed 2016 July 18.

- [36] Denzin N. 1978. *Sociological Methods: A Sourcebook*. New York: McGraw Hill. In Thomas G. 2009. *How to do Your Research Project: A Guide for Students in Education and Applied Social Sciences*. London: Sage. p 111.
- [37] Denzin NK, Lincoln YS. 2000. *Handbook of Qualitative Research*. 2nd ed. London: Sage. p 780.
- [38] Haggis T. 2008. 'Knowledge Must Be Contextual': Some possible implications of complexity and dynamic systems theories for educational research. *Educational Philosophy and Theory*, 40(1): p 158-176. <http://onlinelibrary.wiley.com/doi/10.1111/j.1469-5812.2007.00403.x/abstract> . Accessed 2016 July 18.
- [39] Carlisle D. 2008. *Robo-physio*. Available from: <http://www.csp.org.uk/frontline/article/robo-physio> . Accessed 2016 July 18.
- [40] Harwin WS, Patton JL, Edgerton VR. 2006. Challenges and opportunities for robot-mediated neurorehabilitation. *Proceedings of the IEEE*, 94(9): 1717-1726. In Loureiro RC, Harwin WS, Nagai K, Johnson M. 2011. Advances in upper limb stroke rehabilitation: a technology push. *Medical & Biological Engineering & Computing*, 49(10): p 1103-1118. <http://www.ncbi.nlm.nih.gov/pubmed/21773806> . Accessed 2016 July 18.
- [41] Intercollegiate Stroke Working Party. 2012. *National Clinical Guidelines for Stroke*. 4th ed. London: Royal College of Physicians. Available from: <https://www.rcplondon.ac.uk/sites/default/files/national-clinical-guidelines-for-stroke-fourth-edition.pdf> . Accessed 2016 September 08.
- [42] Fasoli SE, Krebs HI, Stein J, Frontera, WR, Hughes R, Hogan N. 2004. Robotic therapy for chronic motor impairments after stroke: Follow-up results. *Archives of Physical Medicine and Rehabilitation*, 85(7): p 1106-1111. <http://www.ncbi.nlm.nih.gov/pubmed/15241758> . Accessed 2016 July 18.
- [43] Volpe BT, Lynch D, Rykman-Berland A, Ferraro M, Galgano M, Hogan N, Krebs HI. 2008. Intensive sensorimotor arm training mediated by therapist or robot improves hemiparesis in patients with chronic stroke. *Neurorehabilitation and Neural Repair*, 22(3): p 305-310. <http://www.ncbi.nlm.nih.gov/pubmed/18184932> . Accessed 2016 July 18.
- [44] Lum P, Reinkensmeyer D, Mahoney R, Rymer WZ, Burgar C. 2002. Robotic devices for movement therapy after stroke: current status and challenges to clinical acceptance. *Topics in Stroke Rehabilitation*, 8(4): p 40-53. <http://www.ncbi.nlm.nih.gov/pubmed/14523729> . Accessed 2016 July 18.

- [45] Miller EL, Murray L, Richards L, Zorowitz RD, Bakas T, Clark P, Billinger SA. 2010. Comprehensive Overview of Nursing and Interdisciplinary Rehabilitation Care of the Stroke Patient: A Scientific Statement from the American Heart Association. *Stroke*. 41(10): p 2402-2448. <http://stroke.ahajournals.org/content/41/10/2402> . Accessed 2016 July 18.
- [46] Collins S, Britten N, Ruusuvoori J, Thompson A. 2007. Patient Participation In Health Care Consultations: Qualitative Perspectives: Qualitative Perspectives. New York: McGraw-Hill International. 39.
- [47] CSP. 2012. Quality Assurance Standards for Physiotherapy Service Delivery. Available from: [http://www.csp.org.uk/sites/files/csp/secure/quality\\_assurance\\_standards\\_summary\\_060213.pdf](http://www.csp.org.uk/sites/files/csp/secure/quality_assurance_standards_summary_060213.pdf) .
- [48] Krebs HI, Hogan N. 2012. Robotic Therapy: The Tipping Point. *American Journal of Physical Medicine & Rehabilitation/Association of Academic Physiatrists*, 91(11), 290-297. [https://www.researchgate.net/publication/232646524\\_Robotic\\_Therapy\\_The\\_Tipping\\_Point](https://www.researchgate.net/publication/232646524_Robotic_Therapy_The_Tipping_Point) . Accessed 2016 July 19.
- [49] Liddell A, Adshead S, Burgess E. 2008. Technology in the NHS: Transforming the patient's experience of care. Available from: [http://www.kingsfund.org.uk/sites/files/kf/Technology-in-the-NHS-Transforming-patients-experience-of-care-Liddell-Adshead-and-Burgess-Kings-Fund-October-2008\\_0.pdf](http://www.kingsfund.org.uk/sites/files/kf/Technology-in-the-NHS-Transforming-patients-experience-of-care-Liddell-Adshead-and-Burgess-Kings-Fund-October-2008_0.pdf) .
- [50] Dijkers MP, deBear PC, Erlandson RF, Kristy K, Geer DM, Nichols A. 1991. Patient and staff acceptance of robotic technology in occupational therapy: a pilot study. *Journal of rehabilitation research and development*, 28(2) 33-44. <http://www.ncbi.nlm.nih.gov/pubmed/2066869>. Accessed 2016 July 22.
- [51] Krebs HI, Volpe B, Hogan N. 2009. A working model of stroke recovery from rehabilitation robotics practitioners. *Journal of Neuroengineering and Rehabilitation*, 6(6). <https://jneuroengrehab.biomedcentral.com/articles/10.1186/1743-0003-6-6> . Accessed 2016 July 22.
- [52] Higgs J, Titchen A. 2001. Rethinking the practice-knowledge interface in an uncertain world: A model for practice development. *The British Journal of Occupational Therapy*, 64(11), 526-533. In Porter S. 2013. *Tidy's Physiotherapy*. 15th ed. Oxford: Elsevier. p 5.
- [53] College of Occupational Therapists [COT]. 2015. Code of Ethics and Professional Conduct. Available from:

<https://www.cot.co.uk/sites/default/files/publications/public/CODE-OF-ETHICS-2015.pdf> . Accessed 2016 September 08.

- [54] Porter S. 2013. Tidy's Physiotherapy. 15th ed. Oxford: Elsevier. p 16-17.
- [55] Department of Health [DoH]. 2009. Improving Access, Responding to Patients: A 'how-to' guide for GP practices. Available: [http://www.practicemanagement.org.uk/uploads/access\\_guide/090702\\_improving\\_access\\_responding\\_to\\_patients\\_final.pdf](http://www.practicemanagement.org.uk/uploads/access_guide/090702_improving_access_responding_to_patients_final.pdf) . Accessed 2016 July 22.
- [56] Fasoli SE, Krebs HI, Hogan N. 2004b. Robotic technology and stroke rehabilitation: translating research into practice. *Top Stroke Rehabilitation*, 11(4), 11-19. <http://www.ncbi.nlm.nih.gov/pubmed/15592986> . Accessed 2016 July 22.
- [57] Beddow A. 2010. Physiotherapy Workforce Review. Available: <http://www.cfw.org.uk/publications/cfw-physiotherapy-workforce-review> . Accessed 2016 September 08.
- [58] National Institute for Health and Care Excellence [NICE]. 2013. Stroke Rehabilitation: Long-term rehabilitation after Stroke. CG162. London: National Institute for Health and Care Excellence. <https://www.nice.org.uk/Guidance/cg162> . Accessed 2016 July 22.
- [59] Volpe BT, Ferraro M, Krebs HI, Hogan N. 2002. Robotics in the rehabilitation treatment of patients with stroke. *Current Atherosclerosis Reports*, 4(4), 270-276. <http://www.ncbi.nlm.nih.gov/pubmed/12052277> . Accessed 2016 July 22.
- [60] Lo AC, Guarino PD, Richards LG, Haselkorn JK, Wittenberg GF, Federman DG, Ringer RJ, Wagner TH, Krebs HI, Volpe BT, Bever CT Jr, Bravata DM, Duncan PW, Corn BH, Maffucci AD, Nadea SE, Conroy SS, Powell JM, Huang GD, Peduzzi P. 2010. Robot-assisted therapy for long-term upper-limb impairment after stroke. *New England Journal of Medicine*, 362(19), 1772-1783. <http://www.nejm.org/doi/full/10.1056/NEJMoa0911341> . Accessed 2016 July 22.
- [61] Imms C, Wallen M, Laver K. 2015. Robot assisted upper limb therapy combined with upper limb rehabilitation was at least as effective on a range of outcomes, and cost less to deliver, as an equal dose of upper limb rehabilitation alone for people with stroke. *Australian Occupational Therapy Journal*, 62(1), 74–76. <http://www.ncbi.nlm.nih.gov/pubmed/25649038> . Accessed 2016 July 22.
- [62] Wagner TH, Lo AC, Peduzzi P, Bravata DM, Huang GD, Krebs HI, Ringer RJ, Federman DG, Richards LG, Haselkorn JK, Wittenberg GF, Volpe BT, Bever CT, Duncan PW, Siroka A, Guarino PD. 2011. An Economic Analysis of Robot-Assisted Therapy for Long-Term Upper-Limb Impairment after Stroke. *Stroke*, 42(9). 2630–2632. <http://www.ncbi.nlm.nih.gov/pubmed/21757677> . Accessed 2016 July 22.

- [63] CSP. 2014. NHS digital plan requires physios to 'step outside their comfort zone'. Available from: <http://www.csp.org.uk/news/2014/11/13/nhs-digital-plan-requires-physios-step-outside-their-comfort-zone> . Accessed 2016 September 08
- [64] Department of Health [DoH]. 2014. Major New Report on Digital Technology. Available from: <http://webarchive.nationalarchives.gov.uk/20150402110949/https://www.gov.uk/government/news/major-new-report-on-digital-technology> Accessed 2016 September 08
- [65] Department of Health [DoH]. 2013. The Mandate: A Mandate from the Government to the NHS Commissioning Board: April 2013 to March 2015. Available from: [http://webarchive.nationalarchives.gov.uk/20130922140506/https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/256497/13-15\\_mandate.pdf](http://webarchive.nationalarchives.gov.uk/20130922140506/https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/256497/13-15_mandate.pdf) . Accessed 2016 September 08.