Medical Humanities & Medicina Narrativa
ISBN 979–12–218–0381–5
ISSN 1824-5463
DOI 10.53136/979122180381514
pp. 159-174 (dicembre 2022)

Towards the guidelines: application of technologies, in neuromotor rehabilitation, in order to improve psycho-cognitive skills

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Riassunto: L'adozione delle tecnologie si sta progressivamente diffondendo nel sistema sanitario e sta generando nuove prospettive per il trattamento delle patologie del Sistema Nervoso. In particolare, con la riabilitazione neuro-motoria si stanno sperimentando effetti vantaggiosi correlati all'uso delle nuove tecnologie: esistono prove empiriche del miglioramento della cognizione e della motivazione, nonché dello sviluppo di emozioni positive (Doronzo & Guarini, 2021). Lo scopo della rassegna narrativa è quello di confrontare gli studi che si concentrano sulla riabilitazione neuromotoria per definire i punti in comune e le differenze di questi trattamenti che inducono anche esiti positivi sulle funzioni psico-cognitive.

Il presente studio parte dai risultati del Rapid Evidence Assessment (REA) di Doronzo e Guarini (2021) incentrato sull'indagine degli effetti cognitivi, emotivi e motivazionali dello sviluppo motorio. Tale revisione ha come target i pazienti con disabilità che sono stati trattati mediante l'uso delle nuove tecnologie ai fini della riabilitazione neuromotoria. Le tecnologie adottate sono state divise in realtà virtuale, ambienti di apprendimento ibridi, realtà aumentata e strumenti informatici al servizio della telemedicina. Inoltre, è stata effettuata un'analisi qualitativa dei paper della REA per categorizzare le caratteristiche comuni e le differenze tra i vari trattamenti al fine di definire i fattori che si sono mostrati determinanti per indurre gli effetti della riabilitazione neuromotoria anche su domini diversi da quello motorio.

Si auspica che in futuro si possano realizzare linee guida per l'implementazione di interventi riabilitativi efficaci volti a migliorare sia le funzioni motorie che la motivazione, la cognizione e le emozioni.

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Parole–chiave: riabilitazione neuro-motoria, cognizione, emozioni, tecnologie.

Abastract: The adoption of technologies is gradually spreading in the health care system and generating new perspectives for the treatment of Nervous System disorders. In particular, beneficial effects cor-related to the use of new technologies are being experienced with neuro-motor rehabilitation: there is empirical evidence of improved cognition and motivation, as well as the development of positive emotions (Doronzo & Guarini, 2021). The purpose of the narrative review is to compare studies that concentrate on neuromotor rehabilitation to define the points in comunity and differences of these treatments that also induce positive outcomes on psycho-cognitive functions.

The present study starts from the results of the Rapid Evidence Assess-ment (REA) by Doronzo and Guarini (2021) focusing on the investigation of the cognitive, emotional, and motivational effects of motor development. This review targets patients with disabilities who have been treated through the use of new technologies for the purpose of neuromotor rehabilitation. The technologies adopted were divided into virtual reality, hybrid learning environments, augmented reality, and computer instrumentation serving telemedicine. In addition, a qualitative analysis of the REA papers was effected to categorize the common features and differences among the various treatments in order to define the factors that were shown to be decisive in inducing the ef-fects of neuromotor rehabilitation even on domains other than motor.

It is hoped that guidelines for the im-plementation of effective rehabilitation interventions aimed at improving both motor function and motivation, cognition, and emotions can be realized in the future.

Keywords: neuro-motor rehabilitation, cognition, emotion, technology.

1. Introduction

From the ISTAT data of 2019 it is evident that "In Italy there are 3,150,000 (5.2% of population) people with disabilities – those who suffer from health problems, from serious limitations that prevent them from carry-

ing out everyday activities" (Blangiardo, 2021). The percentage is large, and the increase in people's life expectancy is associated with the increase in the prevalence of physical, mental and cognitive impairments. This unfortunately results in social inequalities and forms of discrimination.

The Covid-19 pandemic is creating collateral damage to people with disabilities. Restrictions imposed to contain the spread of the infection limit the access to many health services, including rehabilitation. This situation is expected to lead to long-lasting negative consequences for people with disabilities, increasing functional limitations and hindering recovery (Toto & Limone, 2019; Boldrini *et al.*,2020). Up to 2.2 million people with disabilities suffer collateral damage in Europe due to restrictions that paralyze the health service (Negrini *et al.*, 2020.

This can lead to future cumulative effects due to the reduction of residual functional capabilities and the consequent increase of people needing assistance. When the emergency ends, the demand for rehabilitation will likely rise due to a wave of patients who were already in need, and of post-Covid-19 patients.

A useful resource for preventing and facing the health care emergency, during and post-Covid, is technology. The innovative tools allow to define individual objectives and practices in rehabilitation, to improve the patient's performance and to tailor the intervention (Strubbia *et al.*, 2020). Technology also helps to provide remote care effectively: tele rehabilitation, for example, allows healthcare professionals to monitor, treat and support patients wherever they are.

Findings suggested several benefits of utilizing technology in TBI rehabilitation including facilitating engagement/adherence, increasing access to therapies, and improving generalizability across settings. There is fairly robust evidence regarding the efficacy of online family problem-solving therapy in improving behavior problems, executive functioning, and family functioning (Wade *et al.*, 2018). Application of movement technology in the rehabilitation of neurological disorders has gained a firm position within a short time span. Virtual-reality training seems to be most promising for regaining motor skills, particularly when adjusted to individual capacities (Geurts *et al.*, 2020).

A phenomenon that is emerging in motor rehabilitation, mediated by technologies, is the improvement of other psychic functions not directly treated: cognition, motivation and emotions. It is not surprising to find

a link between motor development with cognitive performance, positive emotions and motivation.

The review of Zeng *et al.* (Zeng *et al.*, 2017) revealed the influence of physical activity on cognitive development, in particular they found a significant positive change in language learning, school performance, attention and working memory.

It is interesting to notice that when footballers undergo a cognitive and motivational training (for example observing images of motivational arousal) they get a positive influence on their performance during training and this improves competition (Slimani *et al.*, 2016). Such evidence is not surprising: the body and the mind are not separate entities.

In the past, motility had been considered as the source of all forms of intentionality by Merleau-Ponty (Merleau-Ponty, 1945); similarly, De Biran considered it the first principle of knowledge and of the acts of the ego (Canullo, 2015): the body that explores and moves directs the individual to knowledge of the world and of himself.

The studies of Infant Research bring new evidence to the topic: they have reconstructed the early stages of human ontogenesis, demonstrating that the body and the sensory-motor skills are the tools through which the mind is structured.

Philosophy and Psychology for years have speculated and studied the relationship between body and mind and Neuroscience has shown the existence of a correlation between motor skills and cognition, emotions and motivation: many brain areas are involved in both movement and psycho-cognitive functions. Talking of rehabilitation, these findings are crucial for planning interventions in patients with multiple impairments or motor impairments associated with increased depressive mood and poor motivation in therapy. Here below we consider some of the studies that provide evidence of such correlation.

It is acknowledged that the cerebellum participates in motor control and its injuries cause a syndrome called ataxia (impaired coordination of movement). Recent observations, however, reveal the involvement of the cerebellum also in cognition and executive control, with an impact on pathologies such as dyslexia and autism. The cerebellum is therefore crucial for both movement and cognition (Sokolov *et al.*, 2017).

The function of dopamine in subcortical structures is to mediate both motivation and movement (Lohani *et al.*, 2019): both functions are im-

paired in Parkinson's disease which is characterized by damage to dopaminergic neurons in the basal ganglia.

Evidence of the link between emotions and motor functions is recurrent: the results of the 2018 study by Sacchi *et al.* highlight that negative emotionality in newborns and maternal depression negatively affect the babies' motor development; instead, the study of Hamer *et al.* in 2012 reveals the link between regular exercise and stress reduction, better mood and mental health.

The REA (Rapid Evidence Assessment) by Doronzo and Guarini of 2021, is focused on the analysis of the neuropsychological effects (emotional, cognitive and motivational) of motor development, and considers a new variable: the adoption of technology in treatment. There is evidence that rehabilitation/motor habilitation induces the recovery or acquisition of skills different from the treated target skills: in particular, they study cognition and motivation deeply and their improvement is evident. The emotional sphere also seems to come into play, however the evidence is scarce. Beckinghausen and Sillitoe (2019) have shown that Purkinje cells in the cerebellum regulate even non-motor functions such as and emotions why motor skills produce effects on motor skills.

The cognitive, motivational and emotional effects emerge more clearly in the protocols mediated by technologies compared to conventional physiotherapy treatments.

Knowing the correlation between these effects and the motor system means taking charge of the person in a complete and effective way, ensuring a better standard of living.

In fact, Pruneti (2019) recommends a multidimensional approach to the patient, taking into account all the psycho-physical variables, in order to increase the likelihood of recovery: health professionals cannot fail to take a holistic approach to the patient, in many cases using multidisciplinary approaches.

To ensure multiple efficacy on motor, cognitive, emotional and motivational functions through motor rehabilitation, it is necessary to systematically study the use of specific technologies and their effects, to learn more about the therapeutic developing processes, to set goals and tailored sessions, and to identify the specific characteristics of the individuals who can really benefit and get multiple results.

2. Materials and Methods

This work is structured as a narrative review; the choice was determined by the need to produce an immediate response and by the scarcity of scientific literature available on the subject. No previous studies were found focusing on the comparison between motor-technological rehabilitation plans, with the aim of defining the positive motor and psycho-cognitive outcomes.

Narrative review is often misunderstood: it is considered hierarchically secondary research and of lower value than systematic review (Greenhalgh *et al.*, 2018). In fact, narrative review uses a highly technical approach in identifying, evaluating and synthesizing evidence; it generally prefers randomized controlled studies or previous systematic reviews. It provides an important contribution to the rapid understanding of a phenomenon (especially in health care): the main purpose is to answer a specific question in order to follow up on targeted interventions. Evidence-informed experts create opinions related to scientific studies by influential authors. The key role of this kind of reviews is therefore to judge the sample selection, to interpret the evidence and widen knowledge, and to answer questions in order to produce useful answers to clinical practice.

This work intends to compare the studies that have shown cognitive, emotional or motivational effects in motor rehabilitation (mediated by technology). A review focusing on mapping the literature centred on the theme is used to compare the studies. This study is a continuation of the 2021 REA by Doronzo and Guarini: it aims at a discursive synthesis and identification of points in common between the selected studies.

The systematic review privileges only what is common in the results to a rigidly defined subset; the present study, instead, aims at diversities, variations and singularities, a still little explored area. To achieve this goal, a removal of prejudice is necessary so that results are not distorted, and qualitative exercise can lead to authentic knowledge.

The narrative review has one main limitation: it is susceptible to distortions, particularly in the process of selecting sources: the choice of studies to be included depends solely on the individual author who presents the studies he has become aware of over shorter or longer periods of time (Sala *et al.*, 2006).

2.1. *A set of criteria for including and excluding studies*

The research was made on the 4 full-length papers, object of study, of the 2020 REA by Doronzo and Guarini. The aim is to deepen the studies selected from the previous review to study them and detect similarities and differences in order to draw up guidelines in the future. REA contained 12 studies, however our criterion excludes the studies for which only abstracts were present. The condition of inclusion is therefore the full availability of the papers. Furthermore, the study by Lancioni *et al.* (2019) is also excluded as it does not provide the rehabilitation plans in detail, which is an insurmountable obstacle for the investigation of the therapeutic characteristics.

2.2. Research strategy

After selecting the 4 papers of REA, out of 12, some categories were identified to analyse and compare the rehabilitation interventions. The categories are: sample, adopted technology, treatment planning, motor effect, psycho-cognitive effect. This procedure was carried out by two authors independently to ensure maximum objectivity and reduce bias. A summary of the findings was then made.

3. Results

Below there is an analysis of the selected studies.

— Rogers *et al.* (2019) adopted the Elements system to rehabilitate the cognitive functions and the upper limbs of stroke patients. 21 patients were recruited for the study between March 2016 and September 2017: 10 randomized patients were in the experimental group, and 11 randomized patients were in the control group. All participants completed the testing and there were no dropouts or adverse events. Selected from the Sydney hospital rehabilitation department, they were patients with upper limb motor impairment resulting from a unilateral stroke. The inclusion criteria were: ability to communicate, understand and follow commands, and abili-

ty to maintain balance while seated. The exclusion criteria were: a previous history of neurological, psychiatric or neurodevelopmental disorders, loss of visual acuity such as to prevent perception of visual material, being under 18. The Elements virtual rehabilitation system has been combined with traditional treatments. The intervention program included 3 weekly individual sessions of 30/40 minutes per session, for 4 weeks. The effects observed following the treatment refer to significant improvements in the motor function of the affected hand; and psycho-cognitive improvements in general cognitive condition and executive functions.

— Kokkoni *et al.* (2020) aims to evaluate social theory-based motor effects in a paediatric learning environment. The individuals selected for the study are 3 children aged 24, 11 and 10 months. It should be pointed out that the 24-month-old subject can be evaluated, in terms of development, in the same way as the other two subjects since he has Down Syndrome; in this case, in fact, development trajectories follow twice as long as in typically developing children. The technological tool adopted is the Grounded Early Adaptive Rehabilitation (GEAR) system. The treatment involved activities twice a week for 4 weeks for a total of 8 sessions; each session lasted about an hour. After the treatment it was possible to detect effects concerning motor, cognitive and social aspects. In terms of movement the subjects followed the robots even in complex motor tasks and implemented adaptive motor actions to support the robots in achieving the goal. Considering the cognitive and social aspects, there was a sustained visual attention and the subjects reduced the proximity distance with the robots with a consequent increase in the possibility of close interactions.

— Cappagli *et al.* (2019) investigated the effectiveness of audio-motor training in order to improve mobility and spatial cognition in visually impaired children. Participants in the study are 44 visually impaired children aged between 6 and 17; the subjects were assigned to two different sets: the control group and the experimental group. The experimental group was subjected to the Audio Bracelet for Blind Interaction (ABBI) training: a training protocol based on the reinforcement of audio-motor associations and aimed at supporting spatial development in visually impaired children. The interven-

tion program was characterized by a 45 minutes' weekly session and was managed by a rehabilitator. The treatment also included a training of 5 hours per week at home with the support of the caregiver. Both activities, in conjunction, were scheduled for 12 weeks. The control group, on the other hand, carried out psychomotor activities that did not necessarily involve sound localization activities. After the treatments, it was found that spatial performance in visually impaired children improved significantly in the experimental group compared to the control group. In addition, positive effects were also highlighted in the development of the participants' spatial cognition.

— In Burridge *et al.*'s study (2017) the use of wearable sensors is experimented in stroke patients. Participants in the study are 19 stroke victims who were assigned to two different groups: there were 8 patients in the control group and 11 patients in the experimental group; the individuals were also at least 18 years old and met the clinical reference criteria. The technology used is C-Mitt, which is a tool designed to limit the functional movement of the hand, but which allows a sufficient grip to hold a walking aid. From the treatment point of view, the possibility of accessing the program for 21 days was provided: subjects were advised to use it 5 days a week for 3 weeks (for a total of 15 days) twice in one day: morning and evening. The positive effects found refer to the improvement in upper limb functionality, the sense of self-efficacy, confidence in the use of the affected arm and body image.

4. Discussion

Table 1 shows a global view of the characteristics of technological motor rehabilitation programs, which also induce psycho-cognitive improvements. To this aim, the 5 dimensions indicated above are investigated. The analysis performed is qualitative, with no precision or systematic nature, as the samples, rehabilitation programs and technologies adopted differ considerably from each other, and are therefore not comparable. Our exercise aims at photographing the characteristics of these innovative therapies trying to bring out similarities that can be the starting points for the

Table 1. The selected studies are explored by analysing them through 5 dimensions: (1) sample, (2) technology adopted, (3) treatment planning, (4) motor effect, (5) psycho-cognitive effect.

Authors	Sample	Technology adopted	Treatment planning	Motor effect	Psycho-cognitive effect
Rogers *et al.*, **2019**	21 subjects (42-94 years old) with sub-acute stroke.	Elements virtual rehabilitation system combined with traditional treatments.	Three weekly sessions of 30-40 minutes per session for 4 weeks.	The effect size of the experimental group shows statistically better improvements in the motor function of the most affected hand.	The effect size of the experimental group shows improvements in general cognitive status and executive functions.
Kokkoni *et al.*, **2020**	3 subjects of 24, 11 and 10 months old. One of them with Down syndrome and therefore with a development that followed the same timing of the other two subjects.	Grounded Early Adaptive Rehabilitation (GEAR) System: A paediatric learning environment designed to provide motor interventions based on social theory.	Twice a week for four weeks for a total of 8 sessions of approximately one hour per session.	The subjects followed the robots even in complex motor tasks and implemented adaptive motor actions to help the robots achieve the goal.	Improvement of sustained visual attention and reduction of the proximity distance by all subjects towards the robots with a consequent increase in the possibility of close interactions.
Cappagli *et al.*, **2019**	44 visually impaired children aged 6-17, assigned to an experimental or control rehabilitation condition.	Audio Bracelet for Blind Interaction (ABBI): bracelet worn on the wrist with the characteristic of providing audio feedback about body movements to help visually impaired children to build a sense of space.	12weeks training. Subjects assigned to the experimental group performed ABBI training with a weekly session of 45' (for 12 weeks) in the presence of a professional rehabilitator plus training of 5 hours per week at home; the subjects assigned to the control group underwent a conventional training based on psychomotor classes that did not necessarily involve sound localization activities.	The spatial performance, of the visually impaired children included in the experimental training group, improved significantly.	Positive effects on the development of the subjects' spatial cognition.
Burridge *et al.*, **2017**	19 stroke victims distributed between control group (8) and experimental group (11).	C-Mitt: tool designed to limit functional hand movement but allows enough grip to hold a walking aid.	Possibility of access to the program for 21 days. Subjects are advised to use it 5 days a week (for a total of 15 days) twice a day: morning and evening.	Improvements in the functionality of the upper limb.	Positive effects on self-efficacy, confidence in the use of the affected arm and body image.

construction of guidelines for planning effective neuro-motor programs also on psycho-cognitive faculties.

(1) The age range is variable: 10 months – 94 years. This leads us to assume that the adoption of technologies in rehabilitation is valid and effective for infants but also for children, adults and the elderly. The samples have different motor disabilities, but all the research excludes subjects with significant mental disorders and with disabilities that prevent the use of the specific technology. This selection responds to the eventuality that severe mental illness or a disability may affect the rehabilitation process: although technology increases the possibility of reducing disability, it is also true that effectiveness depends on will, commitment and positive relationships with the healthcare professional.

(2) The technologies adopted differ from each other as they are built on specific disabilities. All the tools and rehabilitation programs are adapted to the psycho-physical characteristics of the patient. It is essential to train the subject in the use of technology in order to subsequently envisage positive effects in rehabilitation. Innovative tools do not replace man but enable him, or rehabilitate him, breaking down the limits of disability. These consequences were observed: neuroplastic processes, psycho-cognitive stimulations, increase in endorphin levels through physical activity, pain reduction and acquisition of new psycho-motor skills.

(3) Treatment planning is characterized by intensive and frequent sessions. The literature agrees that higher intensity of therapy is associated with better outcomes (Jette *et al.*, 2005).

The effects were seen with 3-week sessions in the study by Burridge *et al.* (Burridge *et al.*, 2017), although the period appears short-lived, the indications prescribe intensive use of 5 days a week twice a day: morning and evening. Cappagli *et al.* (2019), instead, implement an intervention of at least 12 weeks with 45 minutes of weekly therapy in the clinic and 5 hours independently at home. Kokkoni *et al.* (2020) indicate a rehabilitation frequency of twice a week for four weeks. Finally, Rogers *et al.* (2019) implement three weekly sessions for 4 weeks.

(4) Specific motor effects are observed for the rehabilitation target, for example improvement hand function, but also the development of spatial skills (Rogers *et al.*, 2019) and of adaptation to daily activities by producing new complex movements (Kokkoni *et al.*, 2020). Motor training therefore induces not only a selective improvement of the affected limb,

but also a chain of positive consequences for the whole body about motor functions.

(5) Motor rehabilitation, mediated by technologies, produces specific psycho-cognitive positive consequences depending on the type of rehabilitation, however increased motivation has always been observed. In 3 out of 4 studies, the increase in attentional, spatial and executive cognitive abilities also emerged. Furthermore, in the treatment with C-MITT, an improvement in the sense of self-efficacy and body image is observed, as well as an increase in confidence in motor skills. In the study by Kokkoni *et al.* (2020) children, through the acquisition of motor skills, also develop an interest in social relationships and interactive skills.

5. Conclusions

Literature has shown that physical activity is associated with psycho-cognitive improvements, indeed the results of the meta-analysis by Rodriguez-Ayllon *et al.* (2019) suggest that physical activity interventions can improve mental health. Overwhelming evidence exists that lifelong exercise is associated with a longer health span, delaying the onset of 40 chronic conditions/diseases with psychic or organic origin (Ruegsesser & Booth, 2018). Multidimensional positive effects of physical activity are also beginning to emerge in motor rehabilitation. However, the evidence needs to be systematised and guidelines drawn up for adoption by health professionals.

The guidelines consist of a set of information developed systematically, on the basis of valid knowledge, drawn up in order to make a treatment appropriate, and with a high standard of quality and effectiveness. In clinical practice, guidelines are essential to improve treatment outcomes and provide recommendations and predictions of any problems (Jeete *et al.*, 2005; Toto & Limone, 2019). They can promote evidence-based treatment and follow-up and improve the quality of health care through appropriate decision making. Ensuring organized rehabilitation programs also means being able to guarantee positive results, making economic investments with a high cost-effective.

We hope that new studies can carry out systematic investigations to build guidelines in order to implement effective rehabilitation plans both

on motor skills and on psycho-cognitive ones. We expect that questions will be replied such as: "Are there age groups that respond better to treatments?", "Do personality characteristics affect outcomes?", "Is it possible to quantitatively predict psycho-cognitive results?".

There are still few researches that explore the psycho-cognitive advantages of motor rehabilitation mediated by technologies (Doronzo & Guarini, 2021).

This study demonstrates that there is evidence of the association of motor development with increased motivation and improved mood and cognition.

When a person is cognitively impaired, it is therefore possible to slow down the evolution of the disease through a motor approach. In fact, many studies have shown the effectiveness of physical activity in significantly improving the living conditions of affected persons, with documented effects in the psychological, cognitive (memory and attention), biological, and social spheres (Morghen *et al.*, 2011). The research results of Yamauchi *et al.* (2019) suggested that the achievement of ambulation could facilitate successful cognitive/linguistic development in children with Down syndrome. Furthermore, technology-mediated motor rehabilitation ac- ctivates patients by facilitating psycho-physical achievement (Wei, 2018).

Although the therapeutic plans studied by this review are not comparable due to their diversity, fundamental factors emerge associated with the beneficial outcomes of the treatments: absence of psychiatric illnesses of the patients, intensive and frequent rehabilitation sessions, use of technology to increase motivation and adaptation of instruments to the patient's needs.

5.1. *Limitation*

This narrative review is susceptible to bias, particularly in the process of selecting sources The choice of the studies to be included depends exclusively on the individual author, who presents the studies he has become aware of over a longer or shorter period of time. These studies represent only part of the knowledge accumulated within the medical literature. The expert then selects the studies he has come across, often on the basis of subjective criteria, and gives a purely qualitative description of them. a purely qualitative description.

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