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Overview of Assistive Technologies for Adults in a Minimally Conscious State

An integrative Review

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Abstract

Title: Overview of assistive technologies for adults in a minimally conscious state – An integrative review

Keywords: assistive technology, microswitch, voice output communication aid, minimally conscious state

Background: Through the use of assistive technologies persons in a minimally conscious state could gain an active engagement role.

Objective of the Study: Create an overview of assistive technologies used for rehabilitation interventions, which foster self-determination in adults in a minimally conscious state.

Methods: Through a literature search in the databases CINAHL, PubMed, Web of Science, Cochrane, PsycINFO and Medline publications were selected according to the following criteria: (1) adult persons (18+) with a diagnosis of minimally conscious state, (2) survey of assistive technologies.

Findings: Persons in a minimally conscious state can use microswitches to activate an environmental stimulation or a voice output communication aid.

Relevance to Clinical Practice: Interventions with assistive technologies are of crucial importance because no other intervention focuses on the acquisition of an active engagement role.

Limitations and Recommendations for Further Research: Important results may be missed because publications, which involved beside persons in a minimally conscious state also persons with other disabilities, were excluded. Further research should assess the effects of the devices and investigate other related devices.

Introduction

Nentwig assumed that in Germany 40’000 persons fall into coma for one to two weeks each year (Österreichische Wachkomagesellschaft, 2002). Possible transitions from coma are vegetative state (VS), locked-in syndrome (conscious but paralyzed and speechless (Laureys et al., 2005)) or brain death (Bruno et al., 2011). Persons in VS are awake without having awareness of themselves or their environment (The Multi-Society Task Force on PVS, 1994). This condition can persist or evolve to a minimally conscious state (MCS) (Bruno et al., 2011). A prevalence for VS and MCS of 2.8/100’000 was found in healthcare institutions in France (Saoût et al., 2010). In Austria a prevalence of 1.5/100’000 for MCS was found in nursing homes (Donis et al., 2011). In 2002 MCS was defined for the first time by Giacino:

> To make the diagnosis of MCS, limited but clearly discernible evidence of self or environmental awareness must be demonstrated on a reproducible or sustained basis by one or more of the following behaviours:
>
> - Following simple commands.
> - Gestural or verbal yes/no responses (regardless of accuracy).
> - Intelligible verbalisation.
> - Purposeful behaviour, including movements or affective behaviours that occur in contingent relation to relevant environmental stimuli and are not due to reflexive activity. Some examples of qualifying purposeful behaviour include:
>   - appropriate smiling or crying in response to the linguistic or visual content of emotional but not to neutral topics or stimuli
>   - vocalisations or gestures that occur in direct response to the linguistic content of questions
>   - reaching for objects that demonstrates a clear relationship between object location and direction of reach
>   - touching or holding objects in a manner that accommodates the size and shape of the object
>   - pursuit eye movement or sustained fixation that occurs in direct response to moving or salient stimuli (p. 351)

Some persons remain in a MCS while others emerge from this condition (Bruno et al., 2011). Emergence from MCS is indicated by functional interactive communication and/or functional use of two different objects (Giacino et al., 2002). Not all persons affected from coma go through all these transitions. Some recover rapidly while others remain in a condition for a longer period (Bruno et al., 2011)

Evidence for clinical practice for patients in VS or MCS is rare, but shows that early neurorehabilitation is important for improved outcomes and functional benefits (Elliott et al., 2005; Klingshirn et al., 2015; Hirschberg et al., 2011). Nevertheless care and rehabilitation of these patients is challenging for the interprofessional team due to the passive role of the patients and the resulting dependence on support in all activities of daily living (Puggina et al., 2012). Sattin et al. (2014) show that persons in VS and MCS, when compared, have similar limitations and restrictions in the *Activity and Participation* component of the International Classification of Functioning, Disability and Health (ICF). Through an active role in the rehabilitation process these patients could gain self-determination and autonomy and would be much more likely perceived as fellow citizens (Zieger, 2002). The use of assistive technology (AT) has a positive effect on the *Activity and Participation* component (Bauer et. al, 2011) and therefore on an active engagement role. AT is used to increase, maintain or compensate the functional capacities, with a range of different devices matched to the person's specific needs (Assistive Technology Industry Association, 2016) and can be used by persons with MCS (Lancioni et al., 2012d; 2014). As part of the rehabilitation team occupational therapists use AT to enable people to participate in daily activities, which is their primary goal (American Occupational Therapy Association, 2010).

To date few studies are available that address the use of assistive technologies on adults with MCS. The existing reviews (Klingshirn et al., 2015; Lancioni et al. 2010d; 2011c; 2014) include different levels of consciousness or additional interventions.

Aim of this study

The objective of this systematic review is to create an overview of assistive technologies that can be used for adults in a MCS. Therefore the following research question was made: Which assistive technologies can be used as rehabilitation interventions to foster self-determination in adults with a diagnosis of minimally conscious state?

Method

This study is an integrative literature review. This method allows reception of a comprehensive overview and synthesis of the existing literature on the use of assistive technology for persons in a minimally conscious state (Russell, 2005).

Search Strategy

A systematic literature search according to Guba (2008) was conducted in December 2015 using the databases CINAHL, PubMed, Web of Science, Cochrane, PsycINFO and Medline. The keywords in table 1 were used in different combinations.

Table 1

Keywords

Population		**Intervention**
minimally conscious state post-coma disorder of consciousness acquired brain injury	AND	assistive technology microswitch voice output communication aid speech generated device technology based intervention computer technology computer device

Hand search for articles identified in reference lists was performed as supplement to the electronic search, which did not result in any new relevant findings.

Selection Criteria

The following criteria were defined for inclusion: (1) adult persons (18+) with a diagnosis of minimally conscious state, (2) survey of assistive technology. The languages were limited to German and English. The year of publication was not restricted to be sure to find all existing studies.

Analysis Procedure

The search in all Databases produced a total of 307 publications with 161 duplicates. Screening of titles and abstracts of the remaining 146 publications following the aforementioned criteria resulted in 23 studies. Of these 23 studies 4 full-texts were not available. 8 studies were excluded because of methodological weakness or involvement of participants who had emerged from a MCS. Finally, a total of 11 publications was included. The search is illustrated in figure 1 and the detailed search history is presented in the Appendix.

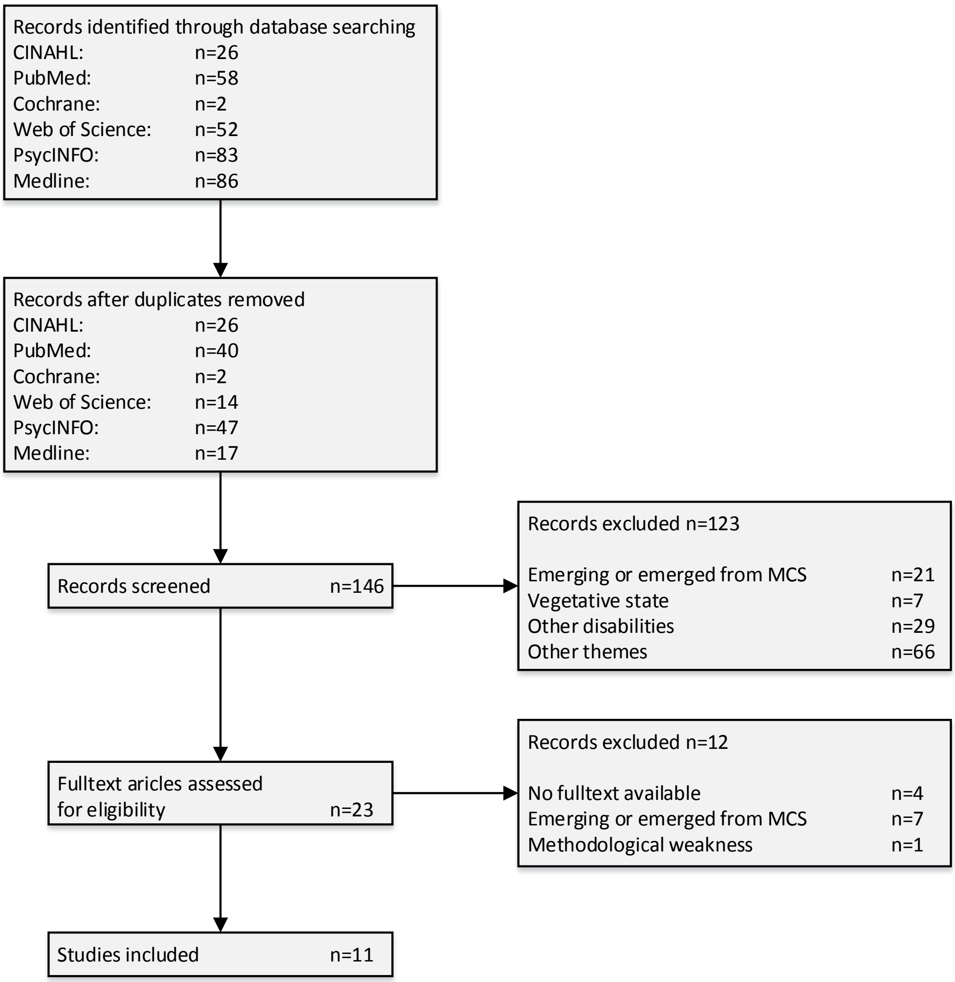

Figure 1. Search history. Adapted from "Preferred Reporting Items for Systematic Reviews and Meta-Analysis: The PRISMA Statement", by Moher D, Liberati A, Tetzlaff J, Altmann DG, 2009, Annals of internal medicine 151(4): 264-269.

All studies included were summarized and evaluated according to Young et al. (2009). The determination of the quality was made according to Bartholomeyczik et al. (2008) and the rating of the evidence was assessed using the 6S model of DiCenso et al. (2009). These analyses were done by one person in cooperation with a senior expert.

Results

In all studies microswitches have been used. Microswitches are small switches, which are extremely sensitive to the slightest movements and are used in automatic-devices (Stevenson, 2010). These switches were connected to an electronic device that was related to an environmental stimulation or a voice output communication aid (VOCA) by which persons were called. To turn on stimulation or a call the participant had to activate a microswitch. Tailored to the participant's abilities various microswitches and responses, e.g. eye blinks or hand movements, were utilized. Tables 3 and 4 provide an overview of the ATs used in the studies. All participants had a diagnosis of MCS and showed pervasive motor disabilities and lack of speech. Stimuli were selected on the basis of family advice and/or direct screening and were presented for 6-20 seconds. More detailed information about the single studies is presented in Table 2.

Table 2

Summaries of the Studies

Reference	Aim	Design / Analysis	Sample	Intervention	Important outcomes
Lancioni et al., 2008	The participant learns (1.) to activate a stimulus through a thumb response and (2.) to call relatives through a dual vocal response.	Single-case study with an ABABNB, an ABB^1B^2 and a CC^1C^2 design Kolmogorov-Smirnov test	n = 1 Score on CRS-R: 11	Programme to learn (1.) the thumb response detected by mini touch sensors to activate video clips (ABABNB design), (2.) a vocal response picked up by microphones to call a sibling or the mother and to choose between these persons (ABB^1B^2 design) and (3.) to choose between thumb and vocal responses (CC^1C^2 design).	Averaged frequencies of responses were higher if stimuli were available and if stimuli were highly attractive. Results are statistically significant ($p<0.01$).
Lancioni et al., 2009a	To gain environmental stimulation through the usage of one or two microswitches and to call for caregivers through a VOCA.	Single-case study with an ABAB and an $ABABB^1$ design Kolmogorov-Smirnov test	n = 4 Score on CRS-R: 9 - 12	Programme to learn the use of one (participant I & III, ABAB design) or two microswitches (participant II, $ABABB^1$ design) to activate environmental stimulation and/or to activate a VOCA to call one (participant III, $ABABB^1$ design) or two persons (participant IIII, $ABABB^1$ design).	Averaged frequencies of responses to the microswitches and the VOCA were higher for all participants if stimuli were available. Results are statistically significant ($p<0.01$).
Lancioni et al., 2009b	To evaluate a programme designed to enable the participants to obtain environmental stimulation through a microswitch or contact to a person through a VOCA.	Single-case study with a modified version of the multi probe design Kolmogorov-Smirnov test	n = 2 Score on CRS-R: 13 and 18	Programme to learn to use (1.) a microswitch through hand pressure (participant I) or hand closure (participant II) to activate a stimulation and (2.) a VOCA through moving a device with the hand (participant I) or moving the big toe (participant II) to require contact with a person and (3.) to choose between the VOCA and the microswitch.	Averaged frequencies of responses to the microswitch and the VOCA were higher for both participants if stimuli were available. Results were statistically significant ($p<0.01$). It seemed that the choice between the two technologies depended on the type of the stimulation.
Lancioni et al., 2009c	To assess a program which enables independent access to environmental	Single-case study with a multi probe design	n = 2 Score on	Programme to acquire the use (1.) of a microswitch through blinks (participant I) or head movement (participant II) to activate	Averaged frequencies of responses to the microswitch and VOCA were higher for both participants if stimuli were available.

Reference	**Aim**	**Design / Analysis**	**Sample**	**Intervention**	**Important outcomes**
	stimulation through a microswitch and contact to one or two persons through a VOCA.	Kolmogorov-Smirnov test	CRS-R: 6 & 12	environmental stimulation and (2.) of a VOCA through hand-closure movements (participant I) or eyelid-closure (participant II) to call for caregivers and (3.) to choose between two caregivers (participant I).	Results are statistically significant (p<0.01). *Participant I:* Averaged frequencies for calls for the mother were higher. Results are statistically significant (p<0.01).
Lancioni et al., 2010a	To evaluate a programme which promotes control of the head posture and access to environmental stimulation through assistive technology.	Single-case study with an ABAB design Kolmogorov-Smirnov test	n = 1 Score on CRS-R: 12	Programme developed to support the learning of closing the zipper of a sweater (participant raised the head), thereby activating an environmental stimulation.	Averaged frequencies of responses were higher if the stimuli were available. Results are statistically significant (p<0.01)
Lancioni et al., 2010b	To assess a programme aimed at enabling the participants to use microswitches to activate environmental stimulation	Single-case study with a modified version of the multi probe design Kolmogorov-Smirnov test	n = 2 Score on CRS-R: 11 & 12	Programme designed to enable the participants to learn the use of two different microswitches through finger movements and head nodding (participant I) or raising the eyelid and touching or pressing the fingers on a pad (participant II) to activate different environmental stimuli.	Averaged frequencies of responses were higher for both participants if the stimuli were available. Results are statistically significant (p<0.01).
Lancioni et al., 2010c	To arrange and assess a programme, which enables the participants to choose among different environmental stimuli and to demand their repetition.	Descriptive single-case study with a non-concurrent multiple baseline design	n = 3 Score on CRS-R: 11 (score of 2 participants unknown)	Programme evolved to support the acquisition of the use of a microswitch trough hand pressure (participant I), eyelid closure (participant II) or hand-closure (participant III) to activate a shortly presented stimulus for 20s and to activate their repetition.	Averaged frequencies of responses were higher for all participants if stimuli were available and if stimuli were the preferred ones. Averaged frequencies of responses to activate repetition per preferred stimulus were 2 (participant I), 10 (participant II) and 14 (participant III) and per non-preferred stimuli low to extremely rarely.
Lancioni et al., 2011a	To evaluate a programme which consists of a microswitch-cluster	Descriptive single-case design with an	n = 1 Score on	Programme to support the acquisition of the use of a microswitch-cluster consisting of a joystick microswitch that had to be activated	Averaged frequencies of responses were higher if the stimuli were available. The mean amount of time per session

Reference	**Aim**	**Design / Analysis**	**Sample**	**Intervention**	**Important outcomes**
	technology and aims to reduce head forward tilting.	ABAB[1]AB[1] design	CRS-R: 12	through manipulation and a tilt microswitch that monitored the head position when activating environmental stimulation.	spent with the head upright increased from less than one minute at the beginning of the study to five minutes at the end of the study.
Lancioni et al., 2011b	To assess a program which enables the participants to choose among different environmental stimuli and to demand their repetition.	Descriptive single-case study with a non-concurrent multiple baseline design	n = 3 Score on CRS-R: 10 - 13	Programme designed to enable the participants to learn the use of a microswitch through eyelid closure to activate a shortly presented stimulus for 20s and to activate their repetition.	Averaged frequencies of responses were higher for all participants if responses were available and if stimuli were the preferred ones. Averaged frequencies of responses to activate repetition per preferred stimulus were 4 (participant I & II) and 6 (participant III) and per non-preferred stimuli were sporadic.
Lancioni et al., 2012a	To assess if a woman at the lower end of the MCS is able to use a microswitch to gain environmental stimulation..	Single-case study with an ABABB[1]C[a]B[1] design Kolmogorov-Smirnov test	n = 1 Score on CRS-R: 8	Programme to acquire the use of a microswitch through hand movement to activate music. In phase B[1] body massage was added to the music.	Averaged frequencies were higher if the responses were available and if the music and the body massage were combined. Results are statistically significant ($p<0.01$).
Lancioni et al., 2012b	To regain the level of adaptive behaviour, to learn additional elements and to drink independent with the use of assistive technology.	Descriptive single-case study with an ABAB[1]B[2]AB[2] design	n = 1 Score on CRS-R: 13	Programme developed to enable the participant to learn (1.) to activate stimuli through object manipulation, (2.) to keep his head upright during object manipulation, (3.) to keep his head upright and the eyes open during object manipulation and (4.) to drink through a straw to activate stimulation.	Averaged frequencies were higher if the responses were available. The participant managed to keep his head upright during the object manipulation and at the end he also managed to keep his eyes open. Additionally, he managed to drink through the straw.

Note. A = Baseline phase (technology was available for the participant, but responses were not followed by stimulation); B/B[1]/B[2]/C/C[1]/C[2] = Intervention phase (technology was available and the responses were followed by stimulation); C[a]/N = Control phase/Noncontingent stimulation phase (technology was available, but the stimuli were applied continuously independent of the response); n = number of participants; CRS-R = Coma Recovery Scale – Revised. Summaries of the studies are presented in further detail in the Appendix.

All included publications are single-case studies with different designs. This study design is appropriate because MCS is a rare phenomenon and the object of investigation is a clinical innovation (Yin, 2014). Samples consist of one to four participants, which are from the whole spectrum of MCS with a range of scores on the CRS from 6 to 18. The small sample size is sparsely representative for the population. Selection of the samples and the reliability and validity of the measuring instruments is not described in the publications. Assistive technology is reliable because all devices used are electronic and can be adapted to the patient's abilities. Validity is achieved through the use of assistive technology. Most results are presented as rounded mean values without standard deviation. The mean is sensitive for extreme values, consequently an interpretation of it without the value of the standard deviation is difficult (Bortz et al., 2010). The Kolmogorov-Smirnov test, which was used in most studies (Lancioni et al., 2008; 2009a; 2009b; 2009c; 2010a; 2010b; 2012a) fitted to calculate the significances. (Bortz et al., 2010). The results are difficult to interpret without knowing the deviation. The publications are well documented and therefore repeatable. All publications are from the same research group, which is a risk for observer bias. The evidence level of all publications is the lowest on the 6s model (DiCenso et al., 2009). Further details of the critical appraisal are presented in the Appendix.

Table 3

Environmental Stimulation

Assistive technology	Response	Stimulation	Publication
pressure microswitch	head turning	comic sketches	Lancioni et al. (2009a)
		film or comic video	Lancioni et al. (2009a)
	head movement	video-clips of sport and music	Lancioni et al. (2009c)
	hand pressure	12 preferred, 4 non preferred stimuli	Lancioni et al. (2010c)
tilt microswitch	head upright	preferred stimuli	Lancioni et al. (2012b; 2011a)
	head nodding	films	Lancioni et al. (2010b)
combination of pressure and tilt microswitch	foot movement	audio-recordings of family members	Lancioni et al. (2009a)
optic mircoswitch	single eye-blink	music	Lancioni et al. (2009a)
	two eye-blinks	music	Lancioni et al. (2009c)
	upward eyelid movement	preferred music	Lancioni et al. (2010b)
	double eyelid closure	12 preferred, 4 non preferred stimuli	Lancioni et al. (2010c; 2011b)
	eyelid closure	12 preferred, 4 non preferred stimuli	Lancioni et al. (2011b)
	object manipulation	preferred stimuli	Lancioni et al. (2012b)
	eyes open	preferred stimuli	Lancioni et al. (2012b)
	drinking from a straw	preferred stimuli	Lancioni et al. (2012b)
touch-sensitive microswitch	thumb movement	video-clips of musical events	Lancioni et al. (2008)
	hand pressure	popular music and songs	Lancioni et al. (2009b)
	finger movement	preferred music	Lancioni et al. (2010b)
	hand movement	music / songs (combined with body massage)	Lancioni et al. (2012a)
	head movement	12 preferred, 4 non preferred stimuli	Lancioni et al. (2010c)
two-membrane microswitch (touching or pressing)	hand closure	popular music / songs and video clips	Lancioni et al. (2009b)
		12 preferred, 4 non preferred stimuli	Lancioni et al (2010c)
	hand stroking / pushing	preferred film	Lancioni et al. (2010b)
wobbling, ball-like device with a joystick microswitch in it	manipulating / moving with the hand	preferred stimuli	Lancioni et al. (2011a)
combination of sensors detecting magnetic fields and a magnetic plaque	closing zipper	preferred stimuli	Lancioni et al. (2010a)

Table 4

Contact with Persons

		Call for one Person	
Assistive technology	**Response**	**Stimulation**	**Publication**
tilt microswitch	arm movement	research assistant (familiarized) approached, talked to him, and presented some stimuli (e.g. pictures, magazines)	Lancioni et al. (2009a)
	big toe lifting	caregiver approached and presented some stimuli (e.g. photos, religious songs)	Lancioni et al. (2009b)
wobble-like microswitch	hand movement	caregiver approached, watched pictures, photos and magazines	Lancioni et al. (2009b)
optic mircoswitch	eyelid closure	research assistant approached, sang preferred songs	Lancioni et al. (2009c)
		Call for two Persons	
Assistive technology	**Response**	**Stimulation**	**Publication**
tilt sensors and optic microswitch	right hand movement / big toe lifting	family member or research assistant (familiarized) approached and told stories or sang and played music	Lancioni et al. (2009a)
cylinder-like pressure mciroswitch	hand-closure movement	family member or research assistant (familiarized) approached, talked to him and presented stimuli (e.g. music, liquids)	Lancioni et al. (2009c)
microphone	emission	relative replied and showed up with stimuli	Lancioni et al. (2008)

Discussion

Due to their passive role, persons in a MCS are dependent on their caregivers for all decisions and activities of daily living (Puggina et al., 2012). It seems therefore essential to investigate new interventions to give them an active role (Naude et al., 2005). This review gives an overview of assistive technologies that can be used for rehabilitation interventions for adults in a MCS to foster their self-determination.

There were two main groups of applications of ATs found: *environmental stimulation* through the use of microswitches and *contact with persons* through the use of VOCAs. In all studies these ATs were matched to participants' individual abilities. Responses through head, hand or finger movements were mostly detected through pressure, tilt or touch-sensitive sensors (Lancioni et al., 2008; 2009a; 2009b; 2009c; 2010b; 2010c; 2011a; 2012a; 2012b). Optic sensors were mostly used to detect eye-blinks or eyelid movements (Lancioni et al., 2009a; 2009c; 2010b; 2010c; 2011b; 2012b). These ATs were also trialed on persons with other disabilities with encouraging evidence for their use (Lancioni et al., 2013). The *environmental stimuli* most frequently used to successfully elicit responses were video clips, films, recordings of family members and music (Lancioni et al., 2008; 2009a; 2009b; 2009c; 2010b; 2010c; 2011b; 2012a). As stimulation to the requested *contact with persons,* caregivers or familiarised research assistants showed up and answered with contact, verbal stimulation and/or the presentation of stimuli (Lancioni et al., 2008; 2009a; 2009b; 2009c). Through this the participant could get social contact. All stimuli used were selected on the basis of family advices and direct screening. Due to that these are according to Abbate et al. (2014) emotional and autobiographic stimuli, which are the most effective ones for persons with disorders of consciousness.

The results of the studies show that the averaged frequencies of responses per participant were higher if the stimuli were available independently of which technology was used. That indicates that every participant was able to learn to use the device. Up to now no other intervention for persons in a MCS could promote learning (Lancioni et al., 2010d). Some studies (Lancioni et al., 2008; 2009c; 2010c; 2011b; 2012a) considered the frequencies of responses for different stimuli offered. They could show a higher averaged frequency of choice for preferred stimuli compared to non-preferred stimuli, for highly attractive stimuli compared to low-power stimuli, for the combination of stimulation with a body massage compared to stimulation without a massage or for one of two persons. That suggests that the participants were able to figure out the differences and to decide whether they want to choose the stimuli or not. In two studies (Lancioni et al., 2010c; 2011b) the participants could additionally ask for the repetition of the stimulus. They repeated almost exclusively the preferred stimuli. Three studies (Lancioni et al., 2010a; 2011a; 2012b) were conducted with the same participant. The aim of these studies was to reduce forward tilting of the head and to promote control of the head posture. The participant managed to raise his head in all the studies, although the programmes were different. Based on this finding, ATs could also be used to improve posture.

All these results have to be considered with high level of caution because of several limitations of the studies. All descriptive results are stated as means, without the value of the standard deviation. As a consequence no statement about the learning processes in the different phases can be made because results could be influenced by extreme values which would have a great influence on the mean (Bortz et al., 2010). Moreover, it is difficult to interpret the significance because information about deviations is missing (Bortz et al., 2010). Additionally, all studies are from the same research group, which can have an impact on the individual's engagement and interaction (Klingshirn et al., 2015) and on the outcomes of the study and their interpretation.

Still, interventions with ATs may be of critical importance for occupational therapists and the interprofessional team, because according to Lancioni et al. (2010d) no other interventions such as transcortical magnetic stimulation, deep brain stimulation, multisensory stimulation or music therapy focus on the patient's acquisition of an active engagement role. This active role is demonstrated by the improvement of the following domains of the *Activity and Participation* component of the ICF (World Health Organisation, 2001) by the use of ATs:

- *Mobility*: The person needs to *change or maintain a body position (d429)* for the activation of a microswitch.
- *Learning and applying knowledge:* By the repetition of the use of a device the person can *acquire a skill (d155)*. Through the activation of environmental stimulation the person can manage purposeful sensory experiences, such as

independently *listening (d110)* to music or audio-recordings and *watching (d115)* video clips or photos independently. If different stimuli are available the person also can *make a decision (d177)* between them.

- *Communication:* Through the acquisition of a microswitch that is connected to a VOCA *a communication device can be used (d360)*.
- *General tasks and demands:* If the person is able to learn to use the AT he or she can *undertake a single task (d210).*

These benefits of ATs are in accordance with the review from Scherer (2005). An active role also means self-determination and autonomy, which encourages motivation and wellbeing (Deci et al., 2008).

Strengths and Limitations

The strengths of this review include the systematic approach, the extensive analysis of the included publications and the overview of all ATs that can be used for rehabilitation interventions for adults with MCS.

Limitations could be, that publications, which involved beside persons in a minimally conscious state also persons with other disabilities, were excluded, because important results may be missed.

Conclusion

Interventions based on ATs (microswiches and VOCAs) are of critical importance for persons in a MCS, due to the active engagement role. But evidence is limited and further investigations are urgently needed. In new research the effects of the devices mentioned above should be examined by another research group and other possible devices should be investigated.

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List of Tables

List of Figures

Number of Words

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Article: 2360

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Thank you.

Eigenständigkeitserklärung

Ich, Anja Graf, erkläre hiermit, dass ich die vorliegende Arbeit selbständig, ohne Mithilfe Dritter und unter Benutzung der angegebenen Quellen verfasst habe.

05.Mai, 2016

Anja Graf

Appendix

Search History

Table A - 1

Search History

Keywords	Database	Results	Exclusion	Relevant Titles	Relevant Abstracts	Relevant Publications
("minimally conscious state" OR post-coma OR "disorder of consciousness") AND ("assistive technology" OR microswitch OR "voice output communication aid" OR voca OR "technology based intervention" OR "speech generated device" OR sgd OR "computer technology" OR "computer device")	CINAHL	26	Emerging or emerged from MCS: 4 Vegetative state: 6 other disabilities : 1 other themes: 2	17	13	Lancioni GE, O'Reilly MF, Singh NN, Buonocunto F, Sacco V, Colonna F., . . . Bosco A (2009a). Technology-based intervention options for post-coma persons with minimally conscious state and pervasive motor disabilities. Developmental Neurorehabilitation 12(1): 24-31. Lancioni GE, Singh NN, O'Reilly MF, Sigafoos J, Buonocunto F, Sacco V, . . . Megna G (2010c). Post-coma persons with motor and communication/consciousne ss impairments choose among environmental stimuli and request stimulus repetitions via assistive technology. Research in developmental disabilities 31(3): 777-783. Lancioni GE, O'Reilly MF, Singh NN, Buonocunto F, Sacco V, Colonna F, . . . Megna G (2010b). Post-coma persons with minimal consciousness and motor disabilities learn to use assistive communication technology to seek environmental stimulation. Journal of Developmental and Physical Disabilities 22(2): 119-129. Lancioni GE, Belardinelli MO, Stasolla F, Singh NN, O'Reilly MF, Sigafoos J, Angelillo MT (2008). Promoting engagement, requests and choice by a man with post-coma

Keywords	Database	Results	Exclusion	Relevant Titles	Relevant Abstracts	Relevant Publications
						pervasive motor impairment and minimally conscious state through a technology-based program. Journal of Developmental and Physical Disabilities 20(4): 379-388. Lancioni GE, Singh NN, O'Reilly MF, Sigafoos J, Buonocunto F, Sacco V, . . . Megna G (2009c). Microswitch- and VOCA-assisted programs for two post-coma persons with minimally conscious state and pervasive motor disabilities. Research in developmental disabilities 30(6): 1459-1467. Lancioni GE, Singh NN, O'Reilly MF, Sigafoos J, Buonocunto F, Sacco V, . . . De Pace C (2009b). Two persons with severe post-coma motor impairment and minimally conscious state use assistive technology to access stimulus events and social contact. Disability and Rehabilitation: Assistive Technology 4(5): 367-372. Lancioni GE, O'Reilly MF, Singh NN, D'Amico F, Ricci I, Buonocunto F (2011a). Microswitch-cluster technology to enhance adaptive engagement and head upright by a post-coma man with multiple disabilities. Developmental neurorehabilitation 14(1): 60-64. Lancioni GE, O'Reilly MF, Singh NN, Oliva D, D'Amico F, Megna G, . . . Sacco V (2010a). A technology-based programme to help a post-coma man with profound multiple disabilities manage stimulation access and posture improvement. Developmental

Keywords	Database	Results	Exclusion	Relevant Titles	Relevant Abstracts	Relevant Publications
						Neurorehabilitation 13(3): 212-216. ***Publications excluded after full-text screening*** **Publications with participants who emerge / emerged from MCS:** Lancioni GE, Singh NN, O'Reilly MF, Sigafoos J, Alberti G, Oliva D, . . . Spica A (2011). Post-coma persons with extensive multiple disabilities use microswitch technology to access selected stimulus events or operate a radio device. Research in developmental disabilities 32(5): 1638-1645. Lancioni GE, Singh NN, O'Reilly MF, Green VA, Buonocunto F, Sacco V, . . . Olivetti Belardinelli M (2014). Microswitch-aided programs with contingent stimulation versus general stimulation programs for post-coma persons with multiple disabilities. Developmental neurorehabilitation 17(4): 251-258. Lancioni GE, Singh NN, O'Reilly MF, Signorino M, Alberti G, Scigliuzzo F, Oliva D (2010). Adapting a computer-assisted program to help a post-coma man with extensive multiple disabilities choose stimulus events. Developmental Neurorehabilitation 13(6): 433-439. Lancioni GE, Singh NN, O'Reilly MF, Sigafoos J, Buonocunto F, D'Amico F, . . . Megna M (2014). Occupation and communication programs for post-coma persons with

Keywords	Database	Results	Exclusion	Relevant Titles	Relevant Abstracts	Relevant Publications
						or without consciousness disorders who show extensive motor impairment and lack of speech. Research in developmental disabilities 35(5): 1110-1118 . **No fulltext available:** Lancioni GE, Singh NN, O'Reilly MF, Sigafoos J, Ricci I, Buonocunto F, Sacco V (2012). Access to Environmental Stimulation Via Eyelid Responses for Persons with Acquired Brain Injury and Multiple Disabilities: a New Microswitch Arrangement. Perceptual & Motor Skills 114(2): 353-362.
("minimally conscious state"[All Fields] OR post-coma[All Fields] OR "disorder of consciousness"[All Fields]) AND ("assistive technology"[All Fields] OR ("technology"[MeSH Terms] OR "technology"[All Fields]) OR microswitch[All Fields] OR "voice output communication aid"[All Fields] OR voca[All Fields])	PubMed	58	Duplicates: 18 Vegetative state: 1 emerging or emerged from MCS: 9 other disabilities: 1 other themes: 24	9	5	Lancioni GE, Singh NN, O'Reilly MF, Sigafoos J, Amenduni MT, Navarro J, . . . Belardinelli MO (2012a). Microswitch technology and contingent stimulation to promote adaptive engagement in persons with minimally conscious state: a case evaluation. Cognitive Processing 13(2): 133-137. ***Publications excluded after full-text screening*** **Methodological weakness:** Lancioni GE, Singh NN, O'Reilly MF, Sigafoos J, Olivetti Belardinelli M (2012). Technology-based intervention to help persons with minimally conscious state and pervasive motor disabilities perform environmentally relevant adaptive behavior. Cognitive Processing 13: 219-22. **Publications with participants who emerge / emerged from MCS:**

Keywords	Database	Results	Exclusion	Relevant Titles	Relevant Abstracts	Relevant Publications
						Lancioni GE, Singh NN, O'Reilly MF, Sigafoos J, Belardinelli MO, Buonocunto, F., . . . Megna, M. (2015). Supporting self-managed leisure engagement and communication in post-coma persons with multiple disabilities. Research in developmental disabilities, 38, 75-83. Lancioni, G. E., Singh, N. N., O'Reilly, M. F., Sigafoos, J., Belardinelli MO, Buonocunto F, . . . Badagliacca F (2012). Promoting adaptive behavior in persons with acquired brain injury, extensive motor and communication disabilities, and consciousness disorders. Research in developmental disabilities: 33(6), 1964-1974. **No fulltext available:** Lancioni GE, Singh NN, O'Reilly MF, Sigafoos J, D'Amico F, Buonocunto F, . . . Damiani S (2015). Assistive technology to help persons in a minimally conscious state develop responding and stimulation control: Performance assessment and social rating. NeuroRehabilitation 37(3): 393-403.
„minimally conscious state“	Cochrane	1	other theme: 1	0	0	
„assistive technology“ AND „disorders of consciousness“	Cochrane	1	other theme: 1	0	0	
(„minimally consciou state“ OR mcs OR	Cochrane	0	0	0	0	

Keywords	Database	Results	Exclusion	Relevant Titles	Relevant Abstracts	Relevant Publications
post-coma) AND („assistive technology“ OR voca OR microswitch)						
TOPIC: ("minimally conscious state" OR "post-coma") AND TOPIC: ("assistive technolog*" OR microswitch OR "voice output communication aid" OR "speech generated device")	Web of Science	52	Duplicates : 38 other themes: 2 emerging or emerged from MCS: 8 other disabilities : 3	8	I	***Publications excluded after full-text screening*** **No fulltext available:** Colonna F, Lancioni GE, Solano JN, Buonocunto F, Sacco V, Megna G (2010). Assistive technology to access stimulus events and social contact for persons with severe post-coma motor impairment and minimally conscious state. European Journal of Neurology 17: 573-573.
(("minimally conscious state" or post-coma or "disorders of consciousness" or "acquired brain injury") and ("assistive technology" or technology or microswitch or "voice output communication aid" or voca or "speech generated device" or sgd)).ab.	PsycINFO	83	Duplicates : 36 other themes: 25 other disabilities : 18	10	4	Lancioni GE, Singh NN, O'Reilly MF, Sigafoos J, d'Amico F, Trubia G, . . . Oliva D (2012). Multiple-microswitch technology to enable adaptive behavior in a man with acquired brain injury and pervasive/multiple disabilities. Life Span and Disability 15(2): 7-19. Lancioni GE, Singh NN, O'Reilly MF, Sigafoos J, Buonocunto F, Sacco V, . . . Megna M (2011). Enabling persons with acquired brain injury and multiple disabilities to choose among environmental stimuli and request their repetition via a technology-assisted program. Journal of Developmental and Physical Disabilities 23(3): 173-182. ***Publications excluded after full-text screening*** **Publications with participants who emerge / emerged from MCS:**

Keywords	Database	Results	Exclusion	Relevant Titles	Relevant Abstracts	Relevant Publications
						Lancioni GE, Singh NN, O'Reilly MF, Sigafoos J, Oliva D, Signorino M, De Tommaso M (2010). Helping a man with acquired brain injury and multiple disabilities manage television use via assistive technology. Clinical Case Studies 9(4): 285-293. **no fulltext available:** Lancioni GE, Saponaro F, Singh NN, O'Reilly MF, Sigafoos J, Oliva D (2010). A microswitch to enable a woman with acquired brain injury and profound multiple disabilities to access environmental stimulation with lip movements. Perceptual & Motor Skills 110(2): 488-492.
(("minimally conscious state" or post-coma or "disorders of consciousness" or "acquired brain injury") and ("assistive technology" or technology or microswitch or "voice output communication aid" or voca or "speech generated device" or sgd)).af.	Medline via Ovid	86	Duplicates: 69 other theme: 11 other disabilities: 6	0	0	

Summaries of the included Studies

All included studies were summarised according to the critical appraisal of Young et al. (2009). The summaries are in the tables A-2 to A-12.

Table A - 2

Summary of the study: Lancioni GE, Belardinelli MO, Stasolla F, Singh NN, O'Reilly MF, Sigafoos J, Angelillo MT (2008). Promoting engagement, requests and choice by a man with post-coma pervasive motor impairment and minimally conscious state through a technology-based program. Journal of Developmental and Physical Disabilities 20(4): 379-388.

	Summary
Objective of the Study	The authors assessed a programme for persons in a MCS designed to support the acquisition of a thumb response to activate a stimulus and of a dual vocal response to call relatives. This programme was based on learning principles.
Design	Single-case study with an ABABNB, an ABB^1B^2 and a CC^1C^2 design
Sample	Luke (30 years old): - severe brain injury after a road accident 6 years prior to the study - MCS - severe motor disability and lack of speech - score on the Coma Recovery Scale-Revised (CRS-R): 11
Intervention	<u>technology</u> - thumb response: 4 mini touch sensors were fixed to the index finger of his right hand, as stimulus a videoclip of a musical event was played - vocal response: sound detecting sensor (throat microphone & airborne microphone → activation needed to be simultaneously), as stimulus his relatives responded verbally and appeared with pairs of stimuli (water and a soft drink, piece of cake and chocolate) → sensors were related to a microprocessor-based electronic system, which activated stimulation → stimuli were chosen due to parents' advise and a preference screening <u>*experimental conditions*</u> **ABABNB** (start of the study, only thumb response) - A (baseline): technology placed, no stimuli available - B (intervention): the responses produced stimuli, a new response within the last 0.5s of the stimlation led to continuity of the video - N (noncontingent stimuation): control phase → independent of the response, videoclips were played at intervals of about 6s **ABB^1B^2** (later in the study, only vocal response) - B (inervention): the responses produced stimuli, the vocalization responses activated a call → sister: shorter than 1.5s, mother: longer than 1.5s. - B^1 (Choice analysis): Mother: same stimuli as in the B phase; sister: low power stimuli (i.e. pictures) - B^2 (Choice analysis): reversed roles **CC^1C^2** (at the end of the study, thumb and vocal response) - C (response combination): thumb and vocalization responses available - C^1 (Choice analysis): mother and sister: same stimuli as in the B phase; thumb response: low-power stimuli

	Summary
	- C^2: highly attractive videotapes, low-power stimuli of mother and sister → 3-5 sessions per day, 10 min thumb response, 20 min thereafter
Results	mean response frequency per session in the phases of the session **ABABNB**: - A: 23 - B: 52, 74 and 72 - N: 40 → Kolmogorov-Smirnov test (KS test): differences between the B and A or N frequencies were statistically significant ($p<0.01$) mean response frequency per session in the phases of the session **ABB^1B^2**: - B: 10 (sister) and 11 (mother) - B^1: 6 (sister) and 16 (mother) - B^2: frequencies were practically reversed → KS test: - differences in overall vocalization frequencies between the A and B phases were statistically significant ($p<0.01$) - similarly significance in the difference in mother and sister's frequencies between B1 and B2 phases. mean response frequency per session in the phases of the session **CC^1C^2**: - C: 70 thumb & 15 vocalization - C1: 44 thumb & 18 vocalization - C2: 75 thumb & 7 vocalization → KS test: differences in thumb- and vocalization response frequencies between C1 and C2 phases were significant ($p<0.01$)
Conclusion / Clinical Implications	The results indicate that Luke was successful in learning new responses. He could build skills, which increased his positive occupation and his active role in terms of communication and choice. Through the use of assistive technology it is possible that persons with minimal level of behaviour get the chance to perform complex responses in terms of environmental control and communication. And the application is plausible for parents and staff. Trough such an approach it is possible to get new, relevant insights about the patient's alertness and level of consciousness.

Note: MCS = Minimally Conscious State; CRS-R = Coma Recovery Scale – Revised. Some parts of the text were taken directly from the study.

Table A - 3

Summary of the study: Lancioni GE, O'Reilly MF, Singh NN, Buonocunto F, Sacco V, Colonna F., . . . Bosco A (2009a). Technology-based intervention options for post-coma persons with minimally conscious state and pervasive motor disabilities. Developmental Neurorehabilitation 12(1): 24-31.

	Summary
Objective of the Study	The authors assessed an approach for persons in a MCS and with pervasive motor disabilities based on learning principles and assistive technology with the following aims: - Study I: To gain environmental stimulation through the use of a microswitch and additionally for one of the participants to ask for contact through a VOCA device. - Study II: For one participant to gain different environmental stimulation through two microswitches and for the other participants to call two caregivers.

	Summary
Design	Single-case study with an ABAB design and an ABABB^1 design
Sample	STUDY I: *Ricky* (26 years old): - severe brain injury due to a road accident 9 month prior to the study - MCS - spastic tetraparesis and limited control of trunk and head - score on CRS-R: 9 *Terry* (52 years old): - cerebellar medulloblastoma at the age of 30, a mengioma at the age of 41 and traumatic brain injury due to a fall 8 month prior to the study - MCS - spastic tetraplesia and limited head and trunk control - score on CRS-R: 12 STUDY II: *Gordon* (45 years old): - cerebral aneurysm rupture 3 years prior to the study - MCS - hypertonic spastic tetraparesis, lack of trunk control, minimal head control - score on CRS-R: 11 *Toby* (18 years old) - brain injury due to a road accident 4 years prior to the study - MCS - spastic tetraparesis, lack of trunk control, minimal head control - score on CRS-R: 9
Intervention	STUDY I <u>technology</u> *Ricky*: - optic microswitch: single eye-blink, as stimulus music was played for 6s *Terry*: - pressure microswitch: placed on the headrest, as stimulus an auditory presentation of comic sketches turned on for 8s - VOCA: tilt sensor fixed on the right arm, response activated a call to a caregiver or a research assistant (familiarized) → they approached, talked to him, engaged him to watching pictures, photos, magazines or videoclips for 15-20min → sensors were related to a microprocessor-based electronic system, which activated stimulation → stimuli were selected on basis of family advice and direct screening <u>experimental conditions</u> *Ricky*: ABAB (A: baseline, B: intervention) *Terry*: ABABB^1: A (baseline: both responses), B (intervention: microswitch response), A (baseline), B (intervention: VOCA response), B^1 (intervention: microswitch and VOCA were alternated) → 5min per session, 3-12 sessions a day STUDY II <u>technology</u> *Gordon*: - pressure microswitch: placed on the wheelchair's headrest, activated through head turning, as stimulus a film or comic video turned on for 20s - tilt and pressure microswitch: activated through foot movement, as stimuli audio-recordings of his wife or son turned on for 20s *Toby*: - VOCA: right hand movement (1) and right big toe lifting (2), detected by optic sensor and tilt devices, turned on a call for a research assistant (familiarized) or a family member → research assistant engaged him in forms of body movements while talking

	Summary
	to him for 20s, family members approached and telled stories while showing pictures or singing and playing music for 20s <u>experimental conditions</u> $ABABB^1$: A (baseline: both responses), B (intervention: focused on the first response), A (baseline), B (intervention: second response), B^1 (intervention: both responses) → 10min per session, 3-9 sessions per day
Results	STUDY I: *Ricky:* mean response frequency per session - A (Baseline): 11 - B (Intervention): 19 - A (Baseline): no number - B (Intervention): 23 *Terry:* mean response frequency per session with the microswitch: - A (Baseline): 7 - B (Intervention): 17 - B^1 (Intervention): similar mean response frequency per session with the VOCA: - A (Baseline): 4 - B (Intervention): 8 - B^1 (Intervention): similar → KS test: differences between baseline and intervention frequencies of responses were statistically significant STUDY II: *Gordon:* mean response frequency per session with the pressure microswitch: - A (Baseline): 4 - B (Intervention): 12 mean response frequency per session with the tilt and pressure microswitch: - A (Baseline): 6 - B (Intervention): 15 mean response frequency per session in phase B^1: 15 *Toby:* mean response frequency per session with the VOCA 1: - A (baseline): 7 - B (intervention): 16 mean response frequency per session with the VOCA 2: - A (baseline): 5 - B (intervention): 16 mean response frequency per session in phase B^1: 18 (VOCA 1 & 2 similarly) → KS test: differences between baseline and intervention frequencies were statistically significant ($p<0.01$)
Conclusion / Clinical Implications	The results indicate that programmes based on learning principles and assistive technologies (microswitch and VOCA) may enable persons in a MCS and with motor disabilities to access environmental stimulation (microswitch) and request social contact (VOCA) by their-own. Through that they get an active role with independent und self-determined occupation. To achieve that it is important that the programme considers interests and motivation of the person.

Note: MCS = Minimally Conscious State; CRS-R = Coma Recovery Scale – Revised; VOCA = Voice Output Communication Aid. Some parts of the text were taken directly from the study.

Table A - 4

Summary of the study: Lancioni GE, Singh NN, O'Reilly MF, Sigafoos J, Buonocunto F, Sacco V, . . . De Pace C (2009b). Two persons with severe post-coma motor impairment and minimally conscious state use assistive technology to access stimulus events and social contact. Disability and Rehabilitation: Assistive Technology 4(5): 367-372.

	Summary
Objective of the Study	The authors assessed a programme for persons in a MCS and with pervasive motor disabilities based on learning principles and assistive technology with the aim to enable the participants to obtain environmental stimulation through a microswitch and contact to a person through a VOCA.
Design	Single-case study with a modified version of a multiple probe design
Sample	*Darren* (35 years old) - brain injury due to a road accident 4.5 years prior to the study - MCS - spastic tetraparesis, limited control of trunk and head, lack of speech - score on CRS-R: 18 *Sally* (60 years old) - bacterial endocarditis 5 month prior to the study - MCS - spastic hemiplegia, limited head and trunk control, lack of speech - score on CRS-R: 13
Intervention	<u>*technology*</u> *Darren*: - touch sensitive device: fixed to the left leg, activated through a hand pressure, as stimuli popular mucis /songs turned on for 7-10s - VOCA: moving with the hand a wobble-like device arranged at the stomach area, activated a call to caregivers → approaching, watching pictures, photos and magazines for 20s → at home, 7min per session, 3-10 sessions per day *Sally*: - two-membrane thin pad: fixed to the palm of the hand, activated through hand closure with the fingers of the right hand touching or pressing on the pad, as stimuli popular music / songs and videoclips were played for 7-10s, - VOCA: moving the big toe of the right foot to activate mini tilt device, call caregivers, which approached, watched photos, television clips, listened to religious text for 15s → at rehabilitation centre, 5min per session, 3-10 sessions per day → stimuli were selected on basis of family advice and direct screening <u>*experimental condition*</u> modified version of the multiple probe design: 1. Baseline I: focused on microswitch or VOCA, any effects 2. Intervention I: microswitch respond 3. Baseline II: VOCA; any effects 4. Intervention II: VOCA response 5. Intervention III: microswitch and VOCA simulaneously
Results	*mean response frequency per session*: - Baseline I: 4 (VOCA and microswitch) - Intervention I: 14 (Darren), 15 (Sally) - Baseline II: 5 (VOCA) - Intervention II: 11 (Darren), 9 (Sally) → KS test: differences between baseline and intervention frequencies of responses were statistically significant

	Summary
	- Intervention III: 12 (Darren), 13 (Sally) (VOCA & microswitch) → they tended to change between VOCA and microswitch in relation to the stimuli available during the session → KS test: differences in percentages of microswitch responses between those specific sets of sessions and the rest of the sessions of Intervention III were significant (p<0,05)
Conclusion / Clinical Implications	The results indicated that this programme based on learning principles and assistive technology (microswitch and VOCA) enabled the participants to access environmental stimulation (microswitch) and request social contact (VOCA) by their-own. Through that they got an active role. Furthermore the application of these devices is plausible for parents and staff.

Note: MCS = Minimally Conscious State; CRS-R = Coma Recovery Scale – Revised; VOCA = Voice Output Communication Aid. Some parts of the text were taken directly from the study.

Table A - 5

Summary of the study: Lancioni GE, Singh NN, O'Reilly MF, Sigafoos J, Buonocunto F, Sacco V, . . . Megna G (2009c). Microswitch- and VOCA-assisted programs for two post-coma persons with minimally conscious state and pervasive motor disabilities. Research in developmental disabilities 30(6): 1459-1467.

	Summary
Objective of the Study	The authors assessed a programme for persons in a MCS and with pervasive motor disabilities based on learning principles and assistive technology with the aim to enable the participants to obtain environmental stimulation through a microswitch and contact to a person through a VOCA.
Design	Single-case study with a multiple probe design
Sample	STUDY I *Eddie* (32 years old) - brain injury due to a work accident 14 month prior to the study - MCS, - optic atrophy, right hemiplegia, limited control of head and trunk - score on CRS-R: 6 STUDY II *Trevor* (33 years old): - cardias ventricular fibrillation followed by anoxic encephalopathy 4 years prior to the study - MCS - hypertonic spastic tetraparesis, lack of trunk control, minimal head control, absence of sphincteric control - score on CRS-R: 12
Intervention	STUDY I *technology* - optic microswitch: directed to the right eye and fixed to his forehead, the responses consisted of a sequence of two blinks occurring within a 2-s interval, as stimulation 8-10s of music was played - VOCA: cylinderlike, pressure device, which was fixed in his left hand, the responses consisted of hand-closure movements activating the left section and hand-closure movements activating the right section, activation lead to a verbal call for his mother or a research assistant (familiarized) → responded him by talking and presenting him different liquids, comic and music items for about 15s

	Summary
	→ sensors detecting the responses were linked to a microprocessor-based electronic control system, which activated the VOCA or the stimulation → stimuli were selected on basis of family advice and direct screening <u>experimental conditions</u> *1. Intervention I microswitch response* - Baseline: presence of microswitch, responses did not effect a stimulus - Intervention I: microswitch was available and produced the effect *2. Intervention I VOCA response* - Baseline and Intervention I as in microswitch response - Choice check: the sections of the cylinderlike pressure device and person called was reversed 3. *Intervention* II VOCA & microwitch response - sessions with VOCA and sessions with microswitch were alternated across days → 3-11 times a day, 5 min per session STUDY II <u>experimental conditions</u> the same procedure as in study I, until Intervention II had to be interrupted because of a arm and shoulder tenotomy → the program was continued with Intervention III (the same as Intervention I with the VOCA)
Results	STUDY I *mean response frequency per session during Intervention I with the microswitch:* - Baseline: 12 - Intervention: 19 *mean response frequency per session during Intervention I with the VOCA:* - Baseline: 5 - Intervention: 10 - Choice Check: 7 (mother) & 4 (research assistant) *mean response frequency per session during Intervention II:* - similar to those obtained during Intervention I → KS test: - differences between baseline and intervention frequencies of microswitch and VOCA responses were statistically significant - differences between the two VOCA responses during Intervention I were not significant, but were significant during choice check and Intervention II STUDY II: *mean response frequency per session during Intervention I with the microswitch:* - Baseline: 6 - Intervention: 20 *mean response frequency per session during Intervention I & III with the VOCA:* - Baseline: 9 - Intervention: 18 → KS test: differences between baseline and intervention frequencies for microswitch and VOCA were statistically significant ($p<0.01$)
Conclusion / Clinical Implications	The results indicate that this programme based on learning principles and assistive technologies (microswitch and VOCA) enabled the participants to access environmental stimulation (microswitch) and request social contact (VOCA). Through that they gained independence to choose preferred stimuli and interaction options through the VOCA.

Note: MCS = Minimally Conscious State; CRS-R = Coma Recovery Scale – Revised; VOCA = Voice Output Communication Aid. Some parts of the text were taken directly from the study.

Table A - 6

Summary of the study: Lancioni GE, O'Reilly MF, Singh NN, Oliva D, D'Amico F, Megna G, . . . Sacco V (2010a). A technology-based programme to help a post-coma man with profound multiple disabilities manage stimulation access and posture improvement. Developmental Neurorehabilitation 13(3): 212-216.

	Summary
Objective of the Study	The authors assessed a technology-based programme for persons in a MCS with the aim to enable the participants to obtain environmental stimulation and to control of the head posture.
Design	Single-case study with an ABAB design
Sample	*a man* (32 years old) - extensive traumatic brain injury 2 years prior to the study - MCS - optic atrophy, right hemiplegia, limited trunk control, lack of speech - score on CRS-R: 12
Intervention	<u>technology</u> The response consisted of closing an open zipper (sweater). The man did that by him-self and it ensured that he raised his head, which was normally forward tilt. The technology consisted of a series of sensors at the man's neck, a sensor on the zipper (activated the aforementioned sensor when the zipper was closed) and a control device that activated some preferred stimuli for 10-15s. → stimuli were selected on basis of direct screening <u>experimental conditions</u> ABAB design 1. A (Baseline I): sweater and technology available, any effects 2. B (Intervention I): responses available 3. A (Baseline II): see Baseline I 4. B (Intervention II): see Intervention I → 5min per session, 3-8 sessions per day
Results	mean response frequency per session: - Baseline I: 4 - Intervention I: 10 - Baseline II: declined - Intervention II: 12 → KS test: differences between baseline and intervention frequencies of responses were statistically significant ($p<.01$)
Conclusion / Clinical Implications	The results suggest that the man was able to access environmental stimulation and that he could exercise control of his head position.

Note: MCS = Minimally Conscious State; CRS-R = Coma Recovery Scale – Revised. Some parts of the text were taken directly from the study.

Table A - 7

Summary of the study: Lancioni GE, O'Reilly MF, Singh NN, Buonocunto F, Sacco V, Colonna F, . . . Megna G (2010b). Post-coma persons with minimal consciousness and motor disabilities learn to use assistive communication technology to seek environmental stimulation. Journal of Developmental and Physical Disabilities 22(2): 119-129.

	Summary
Objective of the Study	The authors assessed a programme for persons with MCS and with pervasive motor disabilities based on learning principles and assistive technologies with the aim to enable the participants to obtain environmental stimuli through microswitches.
Design	Single-case study with a modified version on the multiple probe design
Sample	*Leslie* (56 years old): - primary intracranial hemorrhage 1.5 years prior to the study - MCS - spastic tetraparesis, minimal head control, no trunk control - score on CRS-R: 11 *Sean* (53 years old) - brain injury due to a grave work accident 4 months prior to the study - MCS - spastic tetraparesis, minimal head control, no trunk control - score on CRS-R: 12
Intervention	<u>technology</u> *Leslie:* - microswitch 1: small finger movements affected a touch-sensitive device of a pad microswitch, which was placed on his right hand, as stimulus preferred music was played for 10-15s - microswitch 2: head nodding consisted of any small up-down movement activated a mini-tilt, which was attached on his chin, as stimuli preferred films were played for 10-15s *Sally:* - microswitch 1: raising the left eyelid markedly activate an optic microswitch fixed on his forehead, as stimulation preferred music was played for 10-15s - microswitch 2: finger's touching or pressing on a microswitch pad, as stimulus preferred film were showed for 10-15s → sensors detecting the responses were linked to a microprocessor-based electronic control system, which activated the VOCA or the stimulation → stimuli were selected on basis of family advice and direct screening <u>experimental conditions</u> modified version of the multiple probe design: 1. Baseline I: focused on microswitch 1 or 2, any effects 2. Intervention I: microswitch for the first response 3. Baseline I: other microswitch than in baseline I, any effect 4. Intervention I: other microswitch than in Intervention I 5. Intervention II: microswitch 1 and microswitch 2 were alternated → medical-rehabilitation center, 5min per session, 4-11 sessions per day
Results	*Leslie*: mean response frequency per session: - Baseline I: 5 (microswitch 1), 4 (microswitch 2) - Intervention I: 11 (microswitch 1), 11 (microswitch 2) - Intervention II: 13

	Summary
	→ KS test: differences between baseline and intervention frequencies of responses were statistically significant (p<.01) *Sean:* mean response frequency per session: - Baseline I: 4 (microswitch 1), 6 (microswitch 2) - Intervention I: 12 (microswitch 1), 14 (microswitch 2) - Intervention II: similar to Intervention I → KS test: differences between baseline and intervention frequencies of responses were statistically significant (p<.01)
Conclusion / Clinical Implications	The results indicate that the participants were able to access environmental stimuli through microswitches. Thereby they could leave their isolation, determine their stimuli by their own and increase their performance.

Note: MCS = Minimally Conscious State; CRS-R = Coma Recovery Scale – Revised. Some parts of the text were taken directly from the study.

Table A - 8

Summary of the study: Lancioni GE, Singh NN, O'Reilly MF, Sigafoos J, Buonocunto F, Sacco V, . . . Megna G (2010c). Post-coma persons with motor and communication/consciousness impairments choose among environmental stimuli and request stimulus repetitions via assistive technology. Research in developmental disabilities 31(3): 777-783.

	Summary
Objective of the Study	The authors assessed a programme for persons in a MCS and with pervasive motor disabilities based on microswitches with the aim to enable the participants to choose between environmental stimuli and request their repetition.
Design	Single-case study with a non-current multiple case design
Sample	*Alfred* (22 years old): - Brain injury due to a road accident 2 years prior to the study - MCS - spastic tetraparesis, reduced head control, minimal trunk control, lack of speech - Rancho Level of Cognitive Functioning: 6. Level - Disability Rating Scale: 19 *Edith* (81 years old) - ischemic strokes 3 months prior to the study - MCS - spastic tetraparesis, limited head control, no trunk control, lack of speech - score on the CRS-R: 11 - Rancho Level of Cognitive Functioning: 3. level, *Becky* (51 years old): - rupture of intracranial aneurysm of the left internal carotid atery 4 months prior to the study - MCS - right spastic hemiplegia, tendon-muscle retractions, limited head and trunk control, lack of speech - Rancho Level of Cognitive Functioning: 3. Level - Disability Rating Sclae: 15
Intervention	*technology*

	Summary
	Alfred: hand pressure, detected through a pressure sensor placed in front of him *Edith*: double eyelid closure within a 2s interval, detected through a optic sensor fixed on her forehead over her right eye and/or head movement, detected through a touch sensor placed under her chin *Becky*: hand-closure movement, detected through a sensor placed in her left hand Stimuli: 16 stimuli at each session, 12 preferred stimuli (popular music, instrumental music, family members and friends talking, video-clips of comic gags, family celebrations supplements with verbal comments and music) and 4 non preferred (distorted music and voices), each stimulus was presented for 3s with verbal expression ("and this?" or "want it?"), responses within 6s turned on the stimulus for 20s, a activation within the 20s led to a repetition of a 20s stimulus → stimuli were selected on basis of family interviews, observations and direct screening <u>*experimental conditions*</u> non-concurrent multiple baseline design 1. Baseline: stimulus were presented, activation by the participants did not turn on stimulation 2. Intervention: 3-6 introduction sessions, microswitch-activation within 6s from the presentation of a stimulus sample or from the end of a 20s stimulus episode led to the occurrence or the repetition of the stimulus for 20s → 1-2 sessions per day, lasted until all stimuli samples had been presented or 60min
Results	*mean response frequency per session:* - Baseline: 3 (Edith & Alfred), 5 (Becky) - Intervention: 116 (Alfred), 18 (Edith), 94 (Becky) / per stimulus: 14 (Alfred), 2 (Edith), 10 (Becky) - Intervention (preferred stimuli selected): 8 (Edith & Alfred), 9 (Becky) - Intervention (non-preferred stimuli): fairly low rates (Edith & Becky), extremely rarely (Alfred)
Conclusion / Clinical Implications	The results indicate that programmes based on assistive technologies can enable persons in a MCS and with pervasive motor disabilities to choose among environmental stimuli and ask for their repetition.

Note: MCS = Minimally Conscious State; CRS-R = Coma Recovery Scale – Revised. Some parts of the text were taken directly from the study.

Table A - 9

Summary of the study: Lancioni GE, O'Reilly MF, Singh NN, D'Amico F, Ricci I, Buonocunto F (2011a). Microswitch-cluster technology to enhance adaptive engagement and head upright by a post-coma man with multiple disabilities. Developmental neurorehabilitation 14(1): 60-64.

	Summary
Objective of the Study	The authors assessed a programme for a man in a MCS with the aim to reduce head forward tilting through the use of a microswitch-cluster.
Design	Single-case study with an $ABAB^1AB^1$ design
Sample	*a man* (same as in Lancioni et al., 2010a) (33 years old): - traumatic brain injury 3 years prior to the study - MCS - optic atrophy, right hemiplegia, limited trunk control, lack of speech - score on Coma Recovery Scale: 12

	Summary
Intervention	*technology* manipulating / moving a wobbling, ball-like device and activating a joystick microswitch embedded in it, head position was monitored through tilt devices fixed on a headband that the participant wore during the session, joystick microwsitch and tilt microswitch constituted the microswitch cluster, connected to an electronic control system, turned on preferred stimuli for 10s, new responses were recorded after the stimuli for the previous response ended (10s interval or stimulus interruption provoked by head forward tilting) → stimuli were selected on basis of direct screening *experimental conditions* $ABAB^1AB^1$ design A (Baseline): technology available, any effects B (Intervention I): responses available for the microswitch cluster B^1 (Intervention): only responses performed with the head upright produced stimuli, interrupted if the head did not remain → 5min per session, 3-10 sessions per day

Results	mean response frequency per session:
	- A (Baseline): 7, 3 prompting instances, less than half of the results with head upright, head upright less than 1 minute
	- B (Intervention): 12, 1 prompting instance per session, less than 1/3 with head upright, time with head upright 1 minute
	- B^1 (Intervention): 14, 11 responses with head upright, 2 prompting instances, time with head upright 3 minutes
	- A (Baseline): declined, prompting increased, time with head upright declined
	- B^1:
	    - first half: 17, 1 prompting instance, most with head upright, time with head upright increased to 4 minutes
	    - second half: 21, nearly all responses occurred with head upright, time with head upright increased to 5 minutes during last blocks of sessions

Conclusion / Clinical Implications	The results indicate that the participant was able to reduce head forward tilting through the microswitch-cluster programme. Through such a programme the person can improve unhealthy posture by him- of her-self.

Note: MCS = Minimally Conscious State; CRS-R = Coma Recovery Scale – Revised. Some parts of the text were taken directly from the study.

Table A - 10

Summary of the study: Lancioni GE, Singh NN, O'Reilly MF, Sigafoos J, Buonocunto F, Sacco V, . . . Megna G (2011b). Enabling persons with acquired brain injury and multiple disabilities to choose among environmental stimuli and request their repetition via a technology-assisted program. Journal of Developmental and Physical Disabilities 23(3): 173-182.

	Summary
Objective of the Study	The authors assessed a programme for persons in a MCS and with pervasive motor disabilities with the aim to enable the participants to choose between environmental stimuli through the use of microswitches and request the repetition of this stimuli.
Design	Single-case study with a non-current multiple baseline design
Sample	*Liam* (53 years old):

	Summary
	- brain injury due to a road accident 3 months prior to the study - MCS - flaccid tetraparesis, minimal head & trunk control, lack of speech - Rancho Level of Cognitive Functioning: 3. Level - score on CRS-R: 10 *Desmond* (62 years old) - brainstem ischemic strokes 2 months prior to the study - MCS - moderate psychomotor agitation, flaccid right hemiplegia, limited head control, no trunk control, lack of speech - Rancho Level of Cognitive Functioning: 3. Level - score on CRS-R: 15 *Floyd* (42 years old) - brain injury due to a work accident 14 months prior of the study - MCS - spastic tetraparesis, reduced head and trunk control, lack of speech - Rancho Level of Cognitive Functioning: 3. Level - score on CRS-R: 13
Intervention	<u>*technology*</u> *Liam & Desmond*: prolonged eyelid closure, detected through a optic sensor, fixed on their forehead *Floyd*: double eyelid closure within a 2s interval, detected through a optic sensor fixed on his forehead Stimuli: 16 stimuli at each session, 12 preferred stimuli (popular music, sound tracks and arias, family members and friends talking, video-clips of comic gags, family celebrations supplements with verbal comments and music) and 4 non preferred (distorted music and blurred films), each stimulus was presented for 4s with verbal expression ("and this?" Or "want it?"), responses within 6s turned on the stimulus for 20s, a activation within the 20s led to a repetition of a 20s stimulus, a pause for 6-12s between stimulus end or lack of responding and the next stimulus → stimuli were selected on basis of family interviews, observations and direct screening <u>*experimental conditions*</u> non-concurrent multiple baseline design 1. Baseline: stimulus were presented, activation by the participants did not turn on stimulation 2. Intervention: 3-6 introduction sessions, microswitch-activation within 6s from the presentation of a stimulus sample or from the end of a 20s stimulus episode led to the occurrence or the repetition of the stimulus for 20s → in a rehabilitation clinic
Results	mean response frequency per session: - Baseline: 6 (Liam), 5 (Desmond & Floyd) - Intervention: 39 (Liam), 38 (Desmond), 57 (Floyd) / per stimulus: 4 (Liam & Desmond), 6 (Floyd) - Intervention (preferred stimuli selected): 9-10 - Intervention (non-preferred stimuli): sporadic
Conclusion / Clinical Implications	The results suggest that the participants were able to activate the stimuli, make purposeful choices between preferred and non-preferred stimuli and request the repetition of them.

Note: MCS = Minimally Conscious State; CRS-R = Coma Recovery Scale – Revised. Some parts of the text were taken directly from the study.

Table A - 11

Summary of the study: Lancioni GE, Singh NN, O'Reilly MF, Sigafoos J, Amenduni MT, Navarro J, . . . Belardinelli MO (2012a). Microswitch technology and contingent stimulation to promote adaptive engagement in persons with minimally conscious state: a case evaluation. Cognitive Processing 13(2): 133-137.

	Summary
Objective of the Study	The authors assessed if a persons at the lower end of MCS and with pervasive motor disabilities is able to activate environmental stimulation through a microswitch and if the person can maintain the responding over time.
Design	Single-case study with an $ABABB^1CB^1$ design
Sample	*Nicolette* (53 years old): - brain injury due to a road accident 3 years prior to the study - MCS minus (suggested!!) - severe spastic tetraparesis with tendon-muscle reaction, lack of head control and trunk control - score on the CRS-R: 8
Intervention	<u>technology</u> hand movements, detected through a touch-sensitive pad microswitch (also used in Lancioni et al. 2010c & 2011) placed in her right hand, activated a microprocessor-based electronic control unit, this activated a computer that presented music / songs for 7-8s, which were combined with light body massage stimulation in part of the sessions → music / songs were selected on basis of family recommendations, massage stimulation were added on the assumption that it might be pleasant <u>experimental conditions</u> $ABABB^1CB^1$ A (Baseline): stimulus were presented, activation by the participants did not turn on stimulation B (Intervention): responses were followed by music /songs B1 (Intervention): body massage stimulation was added C (Control phase): musical stimulation and massage were applied continuously during the session → 2-11 sessions per day, 5 min per session
Results	mean response frequency per session: - first A (Baseline): 11 - first B (Intervention): 17 - second A (Baseline): increased after first B - second B (Intervention): 19 - Intervention (preferred stimuli selected): 8 (Edith & Alfred), 9 (Becky) - first B1 (Intervention): 23 - C (control phase): 16 - second B1 (Intervention): 26 → KS test: differences between A and B phases, second B and first B1 phase and B1 and C phase were statistically significant ($p<.01$)
Conclusion / Clinical Implications	The results indicate that the participant was able to use the microswitch and could increase the responding over time.

Note: MCS = Minimally Conscious State; CRS-R = Coma Recovery Scale – Revised. Some parts of the text were taken directly from the study.

Table A - 12

Summary of the study:Lancioni GE, Singh NN, O'Reilly MF, Sigafoos J, D'Amico F, Trubia G, . . . Oliva D (2012b). Multiple-microswitch technology to foster adaptive behavior in a man with acquired brain injury and pervasive/multiple disabilities. Life Span and Disability 15(2): 7-19.

	Summary
Objective of the Study	The authors wanted to survey a programme for a man in a MCS with the aim to restore adaptive level obtained in previous programmes, extend the adaptive behaviour (eyes open) and to establish a new form of adaptive behaviour (drinking).
Design	Single-case study with an $ABAB^1B^2AB^2$ design
Sample	*a man* (34 years old) (same as in Lancioni et al., 2010a; 2011a): - work accident - MCS - optic atrophy, right hemiplegia, reduced trunk control, lack of speech - score on Coma Recovery Scale: 13
Intervention	<u>technology</u> - object manipulation: taking common objects from a container in front of him and placing them inside a box above it, optic sensor in the box - head upright: keeping the head in a vertical position, tilt devices on the arms of an eyeglasses frame - eyes open: keeping the eyelids open expect for periods of less than 2s, optic sensor on the left corner of the eyeglasses' frame - drinking from a straw: drawing water from a small bottle fitted with the straw, optic sensor fixed at the intersection between the small bottle with water and the strwa positioned to the left of the man's face → microswitches connected to a microprocessor-based control system, activated stimuli → stimuli were selected on basis of direct screening <u>experimental conditions</u> $ABAB^1B^2AB^2$ design A (Baseline): technology expect drinking available, any effects B (Intervention): responses available for object manipulation, 10s stimuli B1 (Intervention): responses performed with the head upright and object manipulation produced stimuli B2 (Intervention): focused on object manipulation, head upright and eyes open last B2 (Intervention): CDCD design: C (baseline): microswitch for drinking available, no stimuli; D (intervention): stimuli for drinking available → 5min, 3-10 sessions per day
Results	mean response frequency of objective manipulation per session: - A (Baseline): 5, none with head upright or head upright and eyes open, time with head upright and eyes open very low - B (Intervention): 11, one combined with head upright, none with head upright and eyes open, time with head upright and eyes open very low - B1 (Intervention): 15, most responses combined with head upright, none with head upright and eyes open, time with head upright 230s per session - B2 (Intervention): 15, virtually all of them were combined with head upright and by the end of the phase with head upright and eyes open, time with head upright increased, time with eyes open increased almost to the entire duration of the session - A: responses decreased, half involved head upright, none with head upright and eyes open - B2: 20, virtually all combined with head upright and eyes open - C: 0

	Summary
	- D: 11 - C: increased - D: 15
Conclusion / Clinical Implications	The results indicate that the participant was able to use the microswitches, could increase the time with head upright and managed to drink.

Note: MCS = Minimally Conscious State; CRS-R = Coma Recovery Scale – Revised. Some parts of the text were taken directly from the study.

Critical Appraisal

The included studies were evaluated according to Young et al. (2009). The determination of the quality was made according to Bartholomeyczik et al, (2008) and the rating of the evidence was assessed using the 6S model of DiCenso, et al. (2009).

Table A - 13

Critical Appraisal

	Critical Appraisal
Importance of the theme:	The studies survey an important theme, because no other intervention for persons in a MCS focuses on an active engagement role. Moreover, only a limited number of studies to this topic were conducted.
Design	All included publications are single-case studies with different designs. This study design is appropriate because MCS is a rare phenomenon and the object of investigation is a clinical innovation (Yin, 2014).
Sample	Samples consist of one to four participants, which are from the whole spectrum of MCS with a range of scores on the CRS from 6 to 18. Their condition is characterized by pervasive motor disabilities and lack of speech. The small sample size is sparsely representative for the population. Selection of the samples is not described in the publications.
Measuring instruments	The reliability and validity of the measuring instruments is not described in the publications. Assistive technology is reliable because all devices used are electronic and can be adapted to the patient's abilities. Validity is achieved through the use of assistive technology.
Analysis / Results	Procedure of the data collection is logical and clearly described. Most results are presented as rounded mean values without standard deviation. The mean is sensitive for extreme values, consequently an interpretation of it without the value of the standard deviation is difficult (Bortz et al., 2010). The Kolmogrov-Smirnof test, which was used in most studies (Lancioni et al., 2008; 2009a; 2009b; 2009c; 2010a; 2010b; 2012a), fitted to calculate the significances. (Bortz et al., 2010). The results are difficult to interpret without knowing the deviation.
Repeatability	The publications are repeatable.

Determination of the Quality

Objectivity (Bartholomeyczik et al., 2008)

- All publications are from the same research group, which is a risk for observer bias.
- Most results are presented as rounded mean values without standard deviation. The mean is sensitive for extreme values, consequently an interpretation of it without the value of the standard deviation is difficult (Bortz et al., 2010). The

results of the Kolmogorov-Smirnov test are difficult to interpret without knowing the deviation.

- Procedure and Data collection are comprehensible
- Assistive technology is reliable because all devices used are electronic and can be adapted to the patient's abilities. Validity is achieved through the use of assistive technology

Reliability (Bartholomeyczik et al., 2008)

- Procedure of the data collection is logical and clearly described.
- The publications are repeatable.
- Selection of the samples is not described in the publications.
- Assistive technology is reliable because all devices used are electronic and can be adapted to the patient's abilities.

Validity (Bartholomeyczik et al., 2008)

- The study design (single-case study) is appropriate because MCS is a rare phenomenon and the object of investigation is a clinical innovation (Yin, 2014).
- The small sample size is sparsely representative for the population.
- Validity of the measuring instruments is achieved through the use of assistive technology.

Level of Evidence

The evidence level of all publications is the lowest on the 6s model (DiCenso et al., 2009).

Author Guidelines

Occupational Therapy International has now adopted online manuscript submission and peer review. The new system brings with it a whole host of benefits including:

• Quick and easy submission
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Text arrangement. The text should be divided into sections with headings. The sections should include the following: an introduction describing the problem investigated, incidence/prevalence of the problem, rationale for undertaking the study and a literature review; a methods section describing procedures and research methodology; a results section to indicate objective findings; and a summary or conclusions section. For qualitative studies, literature surveys, theoretical papers, descriptions of occupational therapy programmes and historical reviews, there will be variations in organization.

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Reference style. References should be arranged alphabetically. Where reference is made to more than one work by the same author, published in the same year, identify each citation in the text as follows: (Collins, 1998a), (Collins, 1998b). Where multiple authors are listed in the reference, please cite in the text as 'Maxwell et al. (1999)'. All references must be complete and accurate. Where possible the DOI for the reference should be included at the end of the reference. Online citations should include date of access. References should be listed in the following style:

Website : The Geriatric Website (1999) http://www.wiley.com/oap/ [1 April 1999]

Paper in a journal : Thierry, KL, Spence MJ (2004). A real-life event enhances the accuracy of preschoolers' recall. Applied Cognitive Psychology 18: 297-309. DOI: 10.1002/acp.965

Book : Hare RD, Schalling D (1978). Psychopathic Behaviour: Approaches to Research. New York: Wiley.

Chapter in a book : Oucho JO, Gould WT, Smith FK, Brown PL, Jones RH (1993). Internal migration, urbanization and population distribution. In Foote KA, Hill KH, Martin LG (eds) Demographic Change in Sub-Saharan Africa. Washington DC: National Academy Press pp. 255-296.

Personal communications and unpublished data should not be listed in the reference section but should be given in full in the text.

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