Life Span and Disability XVII, 1 (2014), 89-118

Mental Imagery: rehabilitation through simulation

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Abstract

Mental Imagery can be defined both as a reproduction of cognitive contents of the mind not actually present to sensorial perception, and as the re-elaboration and interpretation of the original perceived data. Motor and athletic rehabilitation and recovery after injuries or traumas, especially in sports, but more generally in physiotherapeutic practice, have shown to be enhanced by mental imagery processes.
Mental imagery has been assumed to be essential for the acquisition of motor skills, but to also be relevant in the involutive phases of adult cognition. In fact, empirical studies indicate that different components of imagery are selectively affected by aging.
This review discusses the neuropsychological bases of mental imagery, focusing on its possible applications to the rehabilitation of deficits from a variety of different causes, including mental deterioration in the elderly.
Simulation techniques, and how they might assist in the accurate assessment of mental imagery skills in order to design optimal learning and/or training interventions, or rehabilitation of motor gestures, are also presented.

Keywords: Mental Imagery; Motor skills; Rehabilitation; Simulation.

Received: January 15, 2014; Accepted: March 25, 2014

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1. Mental Imagery: definition and development.

The use of the term ‘mental imagery’ can be two-fold: it can refer to the reproduction of cognitive contents not actually detectable to sensorial perception, and to the re-elaboration and interpretation of the original perceived data.

Experimental literature (Farah, Gazzaniga, Holtzman, & Kosslyn, 1985; Denis, Logie, Cornoldi, De Vega, & Engelkamp, 2001; Pearson, De Beni, & Cornoldi, 2001; Kosslyn, Thompson, & Ganis, 2006; Joffe, Cain, & Marić, 2007), has identified the essential components of the process of mental imagery as being: the *generation* of images of recently perceived external stimuli that are no longer present, or from long term memory; the *maintenance* of an image in the visuospatial memory buffer; the inspection and verbal *description* of its content; the possibility of *transforming* and *elaborating* the produced image, e.g., by rotating or restructuring it by modifying its contour or shape, or by combining these actions into a mental synthesis that produces new and original models.

Psychophysiological activation often results from the imaginative process in that there are often emotions associated to images, so that the reconstruction or anticipation of images of sensations, not actually present, may generate pleasant experiences or uneasiness, and in some cases, a true pathology.

From what has been said so far, it is clear that mental imagery is not limited to a reproduction of data coming from the senses, from perception or memory; it actively contributes to the (re)construction of a reality that is different from that of the senses, and that is important for the functioning of the mind as a whole.

Imaginative function is considered essential for both spontaneous learning and for knowledge acquisition after specific training (scholastic, artistic, athletic).

The ability to imagine possibilities different from perceived reality contributes to both the cognitive, as well as emotional development of the child (Harris, 2000); and is considered the basis of creative planning and of the capacity to make new discoveries (Finke, 1990; Roskos-Ewoldsen, Intons-Peterson, & Anderson, 1993). The strengthening or enhancement of cognitive functions through mental imagery, in fact, has been studied extensively.

Mental imagery is also considered essential for the acquisition of motor and athletic skills. It creates the capacity to create or recreate an experience from information stored in memory, involving aspects that are similar to sensations and perceptions, and that are controlled willfully by the athlete, even in the absence of the stimuli normally associated to the actual experience (Morris, Spittle, & Watt, 2005). The two characteristics that make up mental imagery ability, therefore, are its vividness and controllability. The first, regards the capacity of the athlete to experience, during the actual motor execution of the gesture. Controllability, instead, regards the facility and accuracy with which mental images are organized and re-interpreted (Moran, 1993).

Novice athletes and experts not only use mental imagery differently in their specific performance (Cumming & Hall, 2002), but also have different brain activations, as has been confirmed by a number of neurophysiological studies (Yarrow, Brown, & Krakauer 2009; Wei & Luo, 2010). Fournier, Deremaux and Bernier (2008), explain these differences in the use of mental imagery in expert athletes as opposed to novices, by referring to three elements: the content (*what* is being visualized), the characteristics (*how* it is being visualized) and the related functions (*why* imagery is being activated).

An extensive amount of literature regards the importance of the use of mental imagery in motor and athletic training and practice (Feltz & Landers, 1983; Murphy, 1994; Martin, Moritz, & Hall, 1999; Ahsen, 2001; Murphy & Martin, 2002; Taktek, 2004; Gregg, Hall, & Nederhof, 2005). Previous and current research findings highlight the positive effects of using cognitive and behavioral routines on athletes' performance and on movement learning processes (Lidor, 2007). As expected, the performance ranking of the coach is significantly related to the quality of mental representations; a finding reported previously in different sports settings. Additionally, players highly qualified in a specific skill (e.g., serve in tennis) possess a similar mental representation to experts' postulation of that skill.

If mental imagery has also been found to be important in child development, it is no less important in the involutive phases of adult cognition. Contradictory data exists in the literature regarding the deterioration of mental imagery abilities in the elderly; some authors consider it as a normal aspect of cognitive decline, while others underline how it is essentially preserved until the very advanced stages of aging (Mason & Smith, 1977; Kosslyn, Margolis, Goldknopf, Daly, & Barrett, 1990; Craik & Dirkx, 1992; Dror & Kosslyn, 1994; Brown, Kosslyn, & Dror, 1998; Palladino & De Beni, 2003; Skoura, Papaxanthis, Vinter, & Pozzo 2005; De Beni, Pazzaglia, & Gardini, 2007; Schott, 2012; Gabbard & Cordoba, 2013; Zapparoli, Invernizzi, Gandola, Verardi, Berlingeri, Sberna *et al.,* 2013).

Many studies argue that the poor performance of imagery in the elderly regards response times rather than their accuracy, and is linked to the complexity of the stimulus when considering working memory as a mediator (Briggs, Raz, & Marks, 1999). Dror and Kosslyn (1994) studied the effects of aging on four components of mental imagery: image generation, maintenance, scanning, and transformation; moreover, image generation can be further fractionated. A representation of the to-be-imaged object can be activated from long-term memory, or the images can be composed sequentially, segment by segment (*activation* versus *composition*).

The authors found that the different components are affected selectively by aging. Older adults showed impairment in image generation, in image activation, in particular, and in rotation with respect to younger adults. In contrast, the elderly were able to compose (the process of generating the segments of a shape, one by one, and scan visual mental images) just as well as young adults. Bruyer and Scailquin (2000), extending these results, demonstrated that in image generation the deficit of the activation stage increases linearly with age, and that there is a complexity effect on accuracy that similarly increases with age. The authors conclude that age per se is not a determinant for image generation.

Kemps and Newson (2005), found that older adults were slower and less accurate than younger adults on all imagery components: image generation, maintenance, scanning and rotation, but showed that manipulations of stimulus complexity produced inconsistent, differential age effects across tasks. According to De Beni, Pazzaglia and Gardini (2007), image generation, maintenance and transformation seem to be differently affected by the type of image and aging. More recently, Kalkstein, Chechsfield, Bollinger and Gazzaley (2011), using fMRI, showed that aging disrupts neural networks that serve mental imagery, and provide evidence of this disruption as a factor in age-related memory decline. Imagery vividness has also been found relevant in normal and impaired aging (Malouin, Richards, & Durand, 2010).

The differences in the results regarding deterioration found in the previously mentioned studies most likely depend on the specific processes being evaluated and the instruments used.

2. The neuropsychological bases of Mental Imagery and the possibilities of its simulation.

Neuropsychological studies have long highlighted the complexity of cerebral activation in mental imagery activity (Farah, 1984, 1985; Denis, Engelkamp, & Richardson 1988; Hampson, Marks, & Richardson, 1990; Sergent, 1990; Tippett, 1992; Kosslyn, 1999; Thompson & Kosslyn, 2000; Kosslyn, Ganis, & Thompson, 2001; Bartolomeo, 2002; Sala, Rama, & Courtney, 2003; Kosslyn, Thompson, Shephard, Ganis, Bell, Danovitch *et al*., 2004; Kosslyn, 2005; Oliverio, 2013). Later studies have shown how imagery, perception and visual memory have overlapping as well as distinct brain locations (Kosslyn, Thompson, & Ganis, 2006; Gardini, De Beni, Cornoldi, Bromiley, & Venneri, 2005; Gardini, Cornoldi, De Beni, & Venneri, 2009; Thompson, Slotnick, Burrage, & Kosslyn, 2009; Slotnick, Thompson, & Kosslyn, 2012; Cichy, Heinzle,

& Haynes, 2012), while Zeman, Della Sala, Torrens, Gountouna, McGonigle and Logie, (2010), have shown in a clinical case, how visuospatial perception and imagery can be functionally separated.

The relationship between the neurobiological mechanisms of perception and imagery is a controversial subject (Ferretti, 1998; Iachini, 2002). Are they analogous and interconnected systems, or are they two different parts of the same system? There is proof that visual imagery has the same neurobiological bases as vision itself (Ishai, Ungerleider, & Haxby, 2000), and that the areas that control spatial perception are also necessary for maintaining mental images active in working memory (Trojano, Conson, Maffei, & Grossi, 2006). The same is true for auditory and verbal stimuli: favorite songs, film dialogues, etc. Images are not only "seen" or "heard" with the eye or the ear of the mind, they are named, linguistically classified, assigned emotional connotations, remembered and transmitted. In fact, the verbal areas of the brain are activated during the recall and semantic qualification of an image in order for it to be memorized.

A recent line of research on mental imagery integrates neuropsychology and cognitive science, and is based on simulation models. Before this, Moulton and Kosslyn (2009) had already established that "all imagery is simulation": imagination is not so much a specific type of mental state, but rather a simulation heuristic, a capacity to reproduce other types of mental states.

Theories in artificial intelligence have considered how mental imagery – an experience that is similar to perceptual experience, but in the absence of the appropriate external stimuli for sensorial perception – can be considered as a type of biological simulation in which the mind represents (simulates) itself in action. This itself represents a kind of off-line cognition involving proprioception that realizes an embodied cognition, especially when imagery involves movement (Jeannerod, 2001; Ziemke, Jirenhed, & Hesslow, 2005; Gallese, 2005; Iachini, 2002, 2011; Di Nuovo, Marocco, Di Nuovo, & Cangelosi, 2011).

Mental chronometry studies confirm this hypothesis, showing how the time employed in imagining a movement is correlated to the time necessary to physically execute it, suggesting that real movements and imagined ones are functionally similar (Decety & Michel, 1989; Decety, Jeannerod, & Prablanc 1989; Decety & Jeannerod, 1995; Jeannerod, 1995; Denis & Kosslyn, 1999; Calmels & Fournier, 2001; Reeds, 2002; Guillot & Collet, 2005; Calmels, Holmes, Lopez, & Naman, 2006). On a neuropsychological level, the primary motor cortex is active during the production of motor images (Jeannerod, 1994, 2001). Other neurophysiological studies have confirmed the substantial overlap between patterns of activation for real movements and imagined ones (Wuyam, Moosavi, Decety, Adams, Lansing, & Guz, 1995; Szameitat, Shen, & Sterr, 2007).

Neuroimaging studies have shown how motor areas of the brain, such as the premotor and parietal areas, are involved in both real as well as imagined movements (Holper, Scholkmann, Shalom, & Wolf, 2012).

Cognitive neuroscience research has also investigated the neural mechanisms of motor imagery in the control of action (e.g. de Lange, Roelofs, & Toni, 2008), and has found similar results to those concerning visual imagery and visual perception and how they recruit similar brain regions (Ganis, Thompson, & Kosslyn, 2004).

Several studies have made use of the motor expertise model to investigate the link between the action execution and action perception network (Calvo-Merino, Glaser, Grezes, Passingham, & Haggard, 2005; Calvo-Merino Grezes, Glaser, Passingham, & Haggard, 2006; Orgs, Dombrowski, Heil, & Jansen-Osmann, 2008) and motor learning (Cross, Hamilton, & Grafton, 2006).

The activity related to static movement creation showed a very similar pattern of activity to the imagery creation tasks, showing how important imagery creation is in movement creation (May, Calvo-Merino, deLahunta, McGregor, Cusack, Owen *et al.,* 2011).

The only major difference found between movement and imagery creation was an increased activation of the right inferior frontal gyrus, which has been associated with representations of goal - directed actions in movement observation and execution (Iacoboni, Woods, Brass, Bekkering, Mazziotta, & Rizzolatti, 1999). Moreover, this area has also been related to inhibition of prepotent responses (Christopoulos, Tobler, Bossaerts, Dolan, & Schultz, 2009), but also in a multiple-demand network (Duncan, 2010), which is activated by many different cognitive demands including perceptual difficulty, novelty, and response conflict.
It seems that body representation and cognitive integration of perceptual body information are strongly influenced by cognitive motor representations (Bläsing, Schack, & Brugger, 2010). Based on these and many other studies, a strongly emerging concept in our understanding of human motion is that major interfaces in the architecture of movement are cognitive in nature.

Thanks to these studies, a transition is taking place, taking us from considering “mental imagery as an internal phenomenon, unimodal and primarily visual and similar to perception, to mental imagery as a multimodal and dynamic phenomenon, based on conscious sensory-motor simulation” (Iachini, 2011, p. 1).

3. Application of Mental Imagery to rehabilitation.

3.1 Motor and athletic rehabilitation.

A related area in which the application of mental imagery to education and rehabilitation is widely used, is in the field of sports (Sheikh, Sheikh, & Moleski, 1994; Martin, Moritz, & Hall, 1999; Sordoni, Hall, & Forwell, 2000; Ahsen, 2001; Hall, 2001; Cumming & Hall, 2002; Murphy & Martin, 2002; Benchke, 2004: Gregg, Hall, & Nederhof, 2005; Vealey & Greenleaf, 2006; Fournier, Deremaux, & Bernier, 2008; Holmes & Calmels, 2008).

"Motor imagery refers to the cognitive process through which the mental representation of an action is activated. In essence, this cognitive process represents 'motor activation without execution'. In the applied/rehabilitation context, motor imagery can be used as a standalone intervention, added to other forms of practice or embedded into another form of intervention" (Kranczioch, Zich, Schierholz, & Sterr, 2014, p. 13).

It has been known for some time that at all ages the imagined rehearsal of motor sequences improves real motor execution later on (Mulder, 2007; Maluoin & Richards, 2010). Training using mental imagery is effective in improving motor performance in that it adds, based on internal stimuli, opportune variations in the movements learned (Taktek, 2004; Munzert, Lorey, & Zentgraf, 2009). It is, therefore, applicable to motor education and rehabilitation, and in the training for various types of individual as well as team sports. For example, Smith, Holmes, Whitemore, Collins and Devonport (2001) have shown that the use of mental imagery, in the training phases of athletes engaged in throwing (e.g., a ball) towards a particular target, later improves their actual performance (Mulder, 2007; Maluoin & Richards, 2010). The imagery helps in learning and practicing the technique, in situations in which it might otherwise be impossible; for example, in contexts that are very different from those of the training scenario, or in situations of recovery after an injury (Nideffer, 1985; Morris *et al.,* 2005; Papadelis, Kourtidou-Papadeli, Bamidis, & Albani, 2007).

When an athlete or an individual in the course of rehabilitation concentrates on mental rehearsal, his nervous system behaves in a way that is similar to when that exercise is physically executed. Rehearsal with mental imagery also has an added effect on an emotional level, because it helps to desensitize the anxiety linked to the prediction of unknown competitive situations, or that are potentially stress inducing. Imagery training is even more effective in learning and performance in motor tasks, when it provides information that would not otherwise be available to the subject (Cumming & Ste-Marie, 2001). Schuster, Hilfiker, Amft, Scheidhauer, Andrews, Butler *et al.,* (2011) tested the effects of motor imagery training, in association with actual physical practice, and reviewed the literature on the argument in five different disciplines: Education, Medicine, Music, Psychology and Sports. They took into consideration the detailed descriptions of the mental imagery training sessions, summarized in the acronym *PETTLEP* (*Physical environment, Timing, Task, Learning emotion, Perspective*) and the detailed temporal parameters, the duration of the study, the duration of the intervention (an average of 34 days), the number of training sessions per week (an average of 3 times for 17 minutes) and the total (an average of 178 minutes). The review covered 133 studies that discussed 141 interventions. The interventions that turned out to be the most effective were individual - supervised but not managed - and done in addition to physical practice.

Sport psychologists use the analysis of athletes' mental representations as basis for the compilation of mental training (e.g. imagery) to control the learning process, or to evaluate the effects of a sport psychological intervention. The mental training can be considered vital for different sports, because it allows insights into the mental structure of technical and tactical skills (with or without routines) of individual players or teams.

Imagery and instructional training (routine demand) can be used for learning or optimizing performance routines (Velentzas, Heinen, Tenenbaum, & Schack, 2010).

An important use of mental imagery training is found in rehabilitation after injuries or traumas, especially in sports, but more generally in physiotherapeutic practice.

Cognitive mental imagery training has long been used to facilitate recovery and to potentiate rehabilitative exercises, control pain, and to help the patient foresee a return to normal activity, increasing the positive attitude of the subject (Cupal & Brewer, 2001; Christakou, Zervas, & Lavallee, 2007). Both visual as well as kinaesthetic images are used, adapting them to the particular characteristics of the injury and of the patient (Driediger, Hall, & Callow 2006). It is essential that trainers and rehabilitators evaluate the tendency and capacity of the subject to use motivational and cognitive imagery (Sordoni, Hall, & Forwell, 2000).

In this sector, precise guidelines in the use of mental imagery training are also necessary, so that trainers can apply well founded scientific criteria, rather than just going with exclusively practical knowledge (Bovend'Eerdt, Dawes, Sackley, & Wade, 2012). It is necessary, for example, to associate to mental imagery training, the consideration of variables such as self-efficacy and adherence to treatment (Milne, Hall, & Farwell, 2005; Wesch, Hall, Prapavessis, Maddison, Bassett, Foley *et al.,* 2012). The images to be used need to be chosen carefully in relation to the characteristics of the injured individual, avoiding those that in his subjective experience are associated with weakness, or that his anxiety concerning the "comeback" have more influence (Monsma, Mensch, & Farroll, 2009). Cumming and Williams (2013) have proposed a general model of imagery use in sports, dance, motor exercise and rehabilitation.

3.2 Rehabilitation of disability and deterioration

Among the uses of mental imagery training, of growing importance are those aimed at the enhancement of motor skills for those subjects with disabilities or physical and mental deterioration. For some time now, neurological rehabilitation has put mental imagery practice to good use, in that it has proven its capacity help re-organize functional cerebral processes (Jackson, Lafleur, Malouin, Richards, & Doyon, 2001). At a neuropsychological level, mental imagery practice often results in a re-organization of neuronal systems, and in the activation of plasticity in the involved systems, but the mechanisms by which this happens are yet unclear. Visual imagery systems, however, are considered to be an essential component (Jackson, Lafleur, Malouin, Richards, & Doyon, 2003; Nyberg Eriksson, Larsson, & Marklund, 2006; Olsson, Jonsson, & Nyberg, 2008; Zhang, Xu, Wang, Xie, Guo, Long *et al.,* 2011).

Below, we discuss a number of examples of how mental imagery training has been used in the rehabilitation of deficits from a variety of different causes.

Ever since the studies conducted in the 70's by Symmes (1971) and Lebrato and Ellis (1974), the involvement of mental imagery, among the consequences of brain damage and mental retardation, has been emphasized. Zupnick and Meyer (1975) studied the long-term effects of instructions based on images in facilitating associative learning in retarded individuals.

Courbois (1996) compared the performance on imagery tasks of two groups of adolescents with mental retardation of different etiology, and one group of subjects of normal intelligence but of the same mental age. The two groups with delay had significantly lower performance, but the major deficit was found in the group with organic causes. The author pointed out how these deficits may have repercussions on other cognitive tasks that require the use of mental representation.

The utility of mental imagery training to improve performance in cases of mental retardation has been confirmed, increasing reaction times (Suburg, 1991) as well as improving motor skills (Surburg, Porretta, & Sutlive, 1995); the effect of imagery training together with physical practice increases the accuracy of performance and reduces variability (Porretta & Surburg, 1995).

Mental imagery training was used in the learning of prose in a group of children (ages 7-12) and adults (18-57) with Down Syndrome, confirming its efficacy in improving memorization to a much greater extent than in conditions in which subjects only listened (De La Iglesia, Buceta, & Campos, 2005).

Vicari, Bellucci and Carlesimo (2006), compared two genetic syndromes, Down and Williams Syndrome, in visual perception tasks, visual and spatial imagery and working memory. Performance in the two groups was different in the different tasks, especially with regard to working memory content (visual-spatial information, or information regarding objects), confirming that these abilities are not always affected in genetic syndromes with intellectual disability, and should be evaluated on a case by case basis.

A study by Roskos-Ewoldsen, Conners, Atwell and Prestopnik (2006), showed that young adults with intellectual disability can have an adequate capacity to visualize (the task was to locate landmarks on a map of an island, and mentally travel from one landmark to another). In respect to a similar visual-perceptual task (with the stimulus present), performance was found to be slow in both individuals with disability, and in a control group made up of university students, when landmarks had to be mentally visualized. However, significant differences were not found among the two groups. Based on these results, the authors concluded that individuals with intellectual disability do not have particular deficits in this type of inspection of mental images.

Ulterior proof that the use of imagery can be fruitful in cases of intellectual disability when coupled with physical training, Hemayattalab and Movahedi (2010) found benefits in the sports training of adolescents with mental retardation, being taught how to free throw in basketball after 24 sessions of mental imagery training associated with physical practice.

3.3 Neurological rehabilitation

Even in cases of psychomotor deficits after trauma or other neurological causes, training with mental imagery has shown to be beneficial (Jackson, Lafleur, Malouin, Richards & Doyon, 2001).

The benefits of this type of rehabilitation in the therapeutic treatment of stroke patients have been found in a number of studies (Batson, 2004; Johnson-Frey, 2004; Liu, Chan, Lee, & Hui-Chan 2004; Dickstein, Dunsky, & Marcovitz, 2004; Dunsky, Dickstein, Ariav, Deutsch, & Marcovitz, 2006; de Vries & Mulder, 2007; Holmes, 2007; Page, Levine, & Leonard, 2007; Zimmermann-Schlatter, Schuster, Puhan, Siekierka, & Steurer, 2008; Nilsen, Gillen, & Gordon, 2010); the greatest effects have been found in mental imagery training coupled to relaxation (Driediger, Hall, & Callow, 2006; Evans, Hare, & Mullen, 2006).

Dijkersman, Ietswaart, Johnston and MacWalter (2004), used motor imagery training in a group of 20 patients two years after stroke incidence in which they imagined the affected limb. They found a significant improvement in almost all the motor functions treated and monitored (except the dynamometer), even if general improvement in the control of attention and perception was not found. Sharma, Pomeroy and Baron (2006) also found improvements in motor functions after mental imagery training.

Lee, Song, Lee, Cho and Lee (2011), found an increase in deambulation capacity in stroke patients, after imagery training focused on movement. The improvement, in terms of velocity of deambulation, wideness of step, and strength of support in both the paralyzed side, as well as the controlateral side, was significantly superior in respect to a control group made up of patients that had not engaged imagery training.

In yet another group of stroke patients, afflicted with chronic post-effects, Hong, Choi and Lee (2012) have shown the utility of associating mental imagery training to electromyographic stimulation; a benefit of training mediated by a brain-computer interface in the rehabilitation of these patients was shown by Prasad, Herman, Coyle, McDonough, and Crosbie (2009), and confirmed by Ortner, Irimia, Scharinger and Guger (2012). Also, home-based motor imagery training showed efficacy in gait rehabilitation in post-stroke hemiparesis (Dunsky, Dickstein, Marcovitz, Levy, & Deutsch, 2008).

Steenbergen, Crajé, Nilsen and Gordon (2009), and Steenbergen, Jongbloed-Pereboom, Spruijt and Gordon (2013), not only studied movement execution but also the programming of motor gestures after motor imagery training in a group of children afflicted with hemiplegic, unilateral cerebral paralysis. Their results suggest that beginning this type of training early is highly beneficial.

Even in cases of visual-spatial neglect, imagery training has been found effective (Smania, Bazoli, Piva, & Guidetti, 1997; McCarthy, Graham Beaumont, Thompson, & Pringle, 2002; Welfringer, Leifert-Fiebach, Babinsky, & Brandt, 2011); intensive 4 week training resulted in the long lasting improvement of visual-kinesthetic abilities and in temporal-spatial orientation (Leifert-Fiebach, Welfringer, Babinsky, & Brandt, 2013).

Mental imagery training can help increase motor functions not only in cases of brain damage, but in spinal injury as well (Cramer, Orr, Cohen, & Lacourse, 2007; Roosink & Zijdewind, 2010; Rienzo, Guillot, Rode, & Collet, 2012; Grangeon, Revol, Guillot, Rode, & Collet, 2012), in burn patients (Guillot, Lebon, Vernay, Girbon, Doyon, & Collet, 2009), in Parkinsons, and in alleviating the pain of phantom limbs (Dickstein & Deutsch, 2007; McAvinue & Robertson, 2011).

In the area of child rehabilitation, Joffe, Cain and Marić (2007), applied mental imagery training in a group of children with specific language disorders, bad readers and with low reading comprehension abilities, and in a control group of normally developing children. They obtained significant results in terms of the improvement of comprehension after just brief training.

A standardized training regimen for neuro-rehabilitation has been introduced by Wondrusch and Schuster-Amft (2013). In fact, for some time now, technology-supported protocols have been used in neurological rehabilitation (Morganti, Gaggioli, Castelnuovo, Bulla, Vettorello, & Riva, 2003).

3.4 Rehabilitation of the mentally impaired elderly

Even in cases of cognitive deterioration in the elderly, a number of studies have examined the role of imaginative functions. The importance of the evaluation of visual imagery in Alzheimer's was emphasized by Kosslyn and Dror in 1992, and has been confirmed by our data on elderly patients with and without deterioration, presented in the previous section. Few studies, however, have proven the benefits of using mental imagery training as prevention or treatment in elderly subjects.

Zehnder, Martin, Altgassen and Clare (2009), in a meta-analytic review of the efficacy of memory training in the elderly (including imagery techniques), found contradictory results, most likely due to the different development of imagery components in working memory, that in some cases can negatively affect the efficacy of training (Schott, 2012).

Malouin, Richards and Durand (2010) have argued that even if visual-motor imagery capacity tends to decline with age, in correspondence with the decline of working memory, the vividness of motor imagery is generally preserved in the elderly, and can be exploited in imagery training even in cases of deterioration. This strategy could be extended to training in cases of deterioration, after mild cognitive impairment and in dementia, and in more severe cases, after evaluation of the residual visualization capacities, and of the possibility of applying a training regime based on them.

According to Hussey, Smolinsky, Piryatinsky, Budson and Ally (2012), even if it is true that neurocognitive deficits do not allow patients with Alzheimer caused dementia to perform complex imagery (as also Grossi, Becker and Trojano, 1994, have shown), evidence exists that residual imagery functions can be used in rehabilitation interventions to improve visual recognition abilities.

4. Possible research and intervention developments based on Mental Imagery.

Experimental research can assist in acquiring a deeper understanding, of which specific applications of mental imagery training can be the most helpful for optimal learning, training or rehabilitation of motor gestures.

For example, the possible operational applications deduced by a simulation study using the training of feedforward and recursive artificial neural networks (Di Nuovo, Marocco, Cangelosi, De La Cruz, & Di Nuovo, 2012; Di Nuovo, Marocco, Di Nuovo, & Cangelosi, 2013), are both interesting and useful to our discussion. According to these authors, the integration of mental imagery in the development of the learning of actions in the networks is valid, but primarily for actions that are not very different in complexity and/or difficulty to those actions learned without it. This means that the studying of the learning curve is essential in order to periodically integrate the mental imagery training in a way that does not create too great a discrepancy between what has been learned and what has to be inferred from imagery.

A further line of study focuses on the cognitive background of motor performance in manual action (Schack & Ritter, 2009), particularly during the rehabilitation of hand function after a stroke (Braun, Beurskens, Schack, Marcellis, Oti, Schols *et al.,* 2007; Braun, Kleynen, Schols, Schack, Beurskens, & Wade, 2008).

Schack and Ritter (2013) learned that central costs and interference in manual actions depend solely on how these movements are represented on a cognitive level. They show that dexterity in manual action and task-related object manipulation is accompanied by order formation in memory. Such order formation in action knowledge reduces the cognitive effort required to activate relevant information. The authors underline that representation and learning in motor action may promote relevant bridges between experimental research and cognitive robotics. For an example of this approach applied to the bootstrapping of numerical cognition through motor representations of finger counting in a cognitive robot, see De La Cruz, Di Nuovo, Di Nuovo, & Cangelosi (2014).

In conclusion, mental imagery and mental simulation are fundamental cognitive capabilities that have the potential to improve the performance of complex artificial systems, going beyond simple problem solving tasks, and enhance the next generation of humanoid robots suitable for assisting rehabilitation. For a special issue on mental imagery in artificial cognitive systems and robotics, see Di Nuovo, De La Cruz and Marocco (2013).

This research should be supported by a highly interdisciplinary approach, in which the integration of neuropsychological studies on mental imagery for human action performance is blended with innovative neurocognitive models and emergent robotics technology. This will result in novel engineering principles for the design of technological aids, including humanoid robots, capable of embodied mental simulations, human-like motor performance, and adaptive social interaction through a high-level of awareness. Enhanced possibilities of rehabilitation may stem from technological improvements grounded in cognitive theories of mental imagery.

References

Ahsen, A. (2001). Imagery in sports, general performance and executive excellence. *Mental Imagery, 25* (3-4), 1-46.

Bartolomeo, P. (2002). The relationship between visual perception and visual mental imagery: a reappraisal of the neuropsychological evidence. *Cortex, 38,* 357-378.

Batson, G. (2004). Motor Imagery for Stroke Rehabilitation: Current Research as a Guide to Clinical Practice. *Alternative and Complementary Therapies, 10* (2), 84-89.

Benchke, L. (2004). Mental skills training for sports: a brief review. *Athletic Insight - The Online Journal of Sport Psychology, 6* (1), 1-19.

Bläsing, B., Schack, T., & Brugger, P. (2010). The functional architecture of the human body: assessing body representation by sorting body parts and activities. *Experimental Brain Research, 203,* 119-129.

Bovend'Eerdt, T. J. H., Dawes, H., Sackley, C., & Wade, D. T. (2012). Practical research-based guidance for motor imagery practice in neurorehabilitation. *Disability and Rehabilitation, 34* (25), 2192-2200.

Braun, S. M., Beurskens, A. J. H. M., Schack, T., Marcellis, R. G., Oti, K. C., Schols, J. M., *et al*. (2007). Is it possible to use the SDA-M to investigate representations of motor actions in stroke patients? *Clinical Rehabilitation, 21,* 822-832.

Braun, S. M., Kleynen, M., Schols, J. M., Schack, T., Beurskens, A. J., & Wade, D. T. (2008). Using mental practice in stroke rehabilitation: a framework. *Clinical Rehabilitation, 7,* 579-591.

Briggs, S. D., Raz, N., & Marks, W. (1999). Age-related deficits in generation and manipulation of mental images: I. The role of sensorimotor speed and working memory 2. *Psychology and Aging, 14* (3), 427-435.

Brown, H. D., Kosslyn, S. M., & Dror, I. E. (1998). Aging and scanning of imagined and perceived visual images. *Experimental Aging Research, 24*, 181-194.

Bruyer, R., & Scailquin, J. C. (2000). Effects of aging on the generation of mental images. *Experimental Aging Research, 26* (4), 337-351.

Calmels, C., & Fournier, J. (2001). Duration of physical and mental execution of gymnastic routines. *The Sport Psychologist, 15*, 142-150.

Calmels, C., Holmes, P., Lopez, E., & Naman, V. (2006). Chronometric comparison of actual and imaged complex movement patterns. *Journal of Motor Behavior, 38*, 339-348.

Calvo-Merino, B., Glaser, D. E., Grezes, J., Passingham, R. E., & Haggard, P. (2005). Action observation and acquired motor skills: an FMRI study with expert dancers. *Cortex, 15*, 1243-1249.

Calvo-Merino, B., Grezes, J., Glaser, D. E., Passingham, R. E., & Haggard, P. (2006). Seeing or doing? Influence of visual and motor familiarity in action observation. *Current Biology, 16,* 1905-1910.

Christakou, A., Zervas Y., & Lavallee, D. (2007). The adjunctive role of imagery on the functional rehabilitation of a grade II ankle sprain. *Human Movement Science, 26 (1),* 141-154.

Christopoulos, G. I., Tobler, P. N., Bossaerts, P., Dolan, R. J. & Schultz, W. (2009). Neural Correlates of Value, Risk, and Risk Aversion Contributing to Decision Making under Risk. *Journal of Neuroscience, 26,* 6469–6472.

Cichy, R. M., Heinzle, J., & Haynes, J. D. (2012). Imagery and perception share cortical representations of content and location. *Cerebral Cortex, 22* (2), 372-380.

Courbois, Y. (1996). Evidence for visual imagery deficits in persons with mental retardation. *American Journal on Mental Retardation, 101* (2), 130-148.

Craik, F. I. M., & Dirkx, E. (1992), Age-related differences in three tests of visual imagery. *Psychology of Aging, 7* (4), 661-665.

Cramer, S. C., Orr, E. L., Cohen, M. J., & Lacourse, M. G. (2007), Effects of motor imagery training after chronic, complete spinal cord injury. *Experimental Brain Research, 177,* 2, 233-242.

Cross, E. S., Hamilton, A. F., & Grafton, S. T. (2006). Building a motor simulation de novo: observation of dance by dancers. *Neuroimage, 31,* 1257-1267.

Cumming, J. L., & Ste-Marie, D. M. (2001). The cognitive and motivational effects of imagery training: A matter of perspective. *The Sport Psychologist, 15,* 276-288.

Cumming, J., & Hall, C. (2002). Deliberate imagery practice: The development of imagery skills in competitive athletes. *Journal of Sports Sciences, 20,* 137-145.

Cumming, J., & Williams, S. E. (2013). Introducing the revised applied model of deliberate imagery use for sport, dance exercise, and rehabilitation. *Movement and Sports Sciences - Science et Motricité, 82,* 69-81.

Cupal, D., & Brewer, B. (2001). Effects of relaxation and guided imagery on knee strength, reinjury anxiety and pain following anterior cruciate ligament reconstruction. *Rehabilitation Psychology, 46,* 28-43.

De Beni, R., Pazzaglia, F., & Gardini, S. (2007). The generation and maintenance of visual mental images: evidence from image type and aging. *Brain Cognition, 63* (3), 271-278.

De La Cruz, V. M., Di Nuovo, A., Di Nuovo, S., & Cangelosi, A. (2014). Making fingers and words count in a cognitive robot. *Frontiers Behavioral Neuroscience, 8* (13), 1-12.

De La Iglesia, J. C. F., Buceta, M. J., & Campos, A. (2005). Prose learning in children and adults with Down syndrome: The use of visual and mental image strategies to improve recall. *Journal of Intellectual and Developmental Disability, 30* (4), 199-206.

de Lange, F. P., Roelofs, K., & Toni, I. (2008). Motor imagery: a window into the mechanisms and alterations of the motor system. *Cortex, 44,* 494-506.

de Vries, S., & Mulder, T. (2007). Motor imagery and stroke rehabilitation: A critical discussion. *Journal of Rehabilitation Medicine, 39* (1), 5-13.

Decety, J., Jeannerod, M., & Prablanc, C. (1989). The timing of mentally represented actions. *Behavioral & Brain Research, 34*, 35-42.

Decety, J., & Jeannerod, M. (1995) Mentally simulated movements in virtual reality: does Fitts's law hold in motor imagery? *Behavioral Brain Research, 72,* 127-134.

Decety, J., & Michel, F. (1989). Comparative analysis of actual and mental movement times in two graphic tasks. *Brain Cognition, 11,* 87-97.

Denis, M. Engelkamp, J., & Richardson, J. T. E. (Eds.) (1988). *Cognitive and neuropsychological approaches to mental imagery*. Dordrecht: Nijhoff.

Denis, M., & Kosslyn, S. M. (1999). Scanning visual mental images: A window on the mind. *Cahiers De Psychologie Cognitive-Current Psychology of Cognition, 18* (4), 409-465.

Denis, M., Logie, R. H., Cornoldi, C., De Vega, M. Engelkamp, J. (Eds.) (2001). *Imagery, Language and Visuo-Spatial Thinking*. Hove, UK: Psychology Press.

Di Nuovo, A., De La Cruz, V. M., & Marocco, D. (2013). Special issue on artificial mental imagery in cognitive systems and robotics. *Adaptive Behavior, 21* (4), 217-221.

Di Nuovo, A. G., Marocco, D., Di Nuovo, S., & Cangelosi, A. (2013). Autonomous learning in humanoid robotics through mental imagery. *Neural Networks, 41*, 147-155.

Di Nuovo, A. G., Marocco, D., Cangelosi, A., De La Cruz, V. M., & Di Nuovo, S. (2012). Mental practice and verbal instructions execution: a cognitive robotics study. In *Neural Networks (IJCNN), The 2012 International Joint Conference on Neural Networks,* 1-6.

Di Nuovo, A .G., Marocco, D., Di Nuovo, S., & Cangelosi, A. (2011). A Neural Network model for spatial mental imagery investigation: A study with the humanoid robot platform iCub. In *Neural Networks (IJCNN), The 2011 International Joint Conference on Neural Networks,* 2199-2204.

Dickstein, R., & Deutsch, J.E. (2007). Motor imagery in physical therapist practice. *Physical Therapy, 87,* 942-953.

Dickstein, R., Dunsky, A., & Marcovitz, E. (2004). Motor imagery for gait rehabilitation in post-stroke hemiparesis. *Physical Therapy, 84* (12), 1167-1177.

Dijkerman, H. C., Ietswaart, M., Johnston, M., & MacWalter, R. S. (2004). Does motor imagery training improve hand function in chronic stroke patients? A pilot study. *Clinical Rehabilitation, 18* (5), 538-549.

Driediger, M., Hall, C., & Callow, N. (2006). Imagery use by injured athletes: A qualitative analysis. *Journal of Sports Sciences, 24* (3), 261-271.

Dror, I. E., & Kosslyn, S. M. (1994). Mental imagery and aging. *Psychology of Aging, 9*, 1, 90-102.

Duncan, J. (2010). The multiple-demand (MD) system of the primate brain: Mental programs for intelligent behaviour. *Trends in Cognitive Sciences, 14* (4), 172-179.

Dunsky, A., Dickstein, R., Ariav, C., Deutsch, J., & Marcovitz, E. (2006). Motor imagery practice in gait rehabilitation of chronic post-stroke hemiparesis: Four case studies. *International Journal of Rehabilitation Research, 29* (4), 351-356.

Dunsky, A., Dickstein, R., Marcovitz, E., Levy, S., & Deutsch, J. (2008). Home-based motor imagery training for gait rehabilitation of people with chronic poststroke hemiparesis. *Archives of Physical Medicine and Rehabilitation, 89* (8), 1580-1588.

Evans, L., Hare, R., & Mullen, R. (2006). Imagery use during rehabilitation from injury. *Journal of Imagery Research in Sport and Physical Activity, 1,* 1-21.

Farah, M. J. (1984). The neurological basis of mental imagery: a componential analysis. *Cognition, 18,* 245-272.

Farah, M. J. (1985). Psychophysical evidence for a shared representational medium for visual images and percepts. *Journal of Experimental Psychology, 114,* 93-105.

Farah, M. J., Gazzaniga, M. S., Holtzman, J. D., & Kosslyn, S. M. (1985). A left hemisphere basis for visual mental imagery? *Neuropsychologia, 23*, 115-118.

Feltz, D. L., & Landers, D. M. (1983). The effects of mental practice on motor skill learning and performance: a meta-analysis. *Journal of Sport Psychology, 5*, 25-57.

Ferretti, F. (1998). *Pensare vedendo. Le immagini mentali nella scienza cognitiva*. Roma: Carocci.

Finke, R. A. (1990). *Creative imagery*. Hillsdale: Erlbaum.

Fournier, J. F., Deremaux, S., & Bernier, M. (2008). Content, characteristics and function of mental images. *Psychology of Sport and Exercise, 9* (6), 734-748.

Gabbard, C., & Cordova, A. (2013). Association between imagined and actual functional reach (FR): A comparison of young and older adults. *Archives of Gerontology and Geriatrics, 56,* 487-491.

Gallese, V. (2005). Embodied simulation: from neurons to phenomenal experience. *Phenomenology and the Cognitive Sciences, 4,* 23-48.

Ganis, G., Thompson, W. L., & Kosslyn, S. M. (2004). Brain areas underlying visual mental imagery and visual perception: an fMRI study. *Cognitive Brain Research, 20* (2), 226-241.

Gardini, S., Cornoldi, C., De Beni, R., & Venneri, A. (2009). Cognitive and neuronal processes involved in sequential generation of general and specific mental images. *Psychological Research-Psychologische Forschung, 73* (5), 633–643.

Gardini, S., De Beni, R., Cornoldi, C., Bromiley, A., & Venneri, A. (2005). Different neuronal pathways support the generation of general and specific mental images. *NeuroImage, 27* (3), 544-552.

Grangeon, M., Revol, P., Guillot, A., Rode, G., & Collet, C. (2012). Could motor imagery be effective in upper limb rehabilitation of individuals with spinal cord injury? *A case study. Spinal Cord, 50* (10), 766-771.

Gregg, M., Hall, C., & Nederhof E. (2005). The imagery ability, imagery use and performance relationship. *The Sport Psychologist, 19*, 93-99.

Grèzes, J., & Decety, J. (2001). Functional anatomy of execution, mental simulation, observation, and verb generation of actions: a meta-analysis. *Human Brain Mapping, 12* (1), 1-19.

Grossi, D., Becker, J. T., & Trojano, L. (1994). Visuospatial imagery in Alzheimer disease. *Perceptual and Motor Skills, 78* (3), 867-874.

Guillot, A., & Collet, C. (2005). Duration of mentally simulated movements: A review, *Journal of Motor Behavior, 37*, 10-19.

Guillot, A., Lebon, F., Vernay, M., Girbon, J. P., Doyon, J., & Collet, C. (2009). Effect of motor imagery in the rehabilitation of burn patients. *Journal of Burn Care and Research, 30* (4), 686-693.

Hall, C. R. (2001). Imagery in sport and exercise. In R. Singer, H. A. Hausenblas, C. M. Janelle (Eds.), *Handbook of sport psychology*. (pp. 529-549). New York: Wiley.

Hampson, P. J., Marks, D. F., & Richardson, J. T. E. (Eds.) (1990). *Imagery: current developments*, London: Routledge.

Harris, P. L. (2000). *The work of imagination. Malden: Blackwell. Tr. It. L'immaginazione del bambino,* Cortina: Milano, 2008.

Hemayattalab, R., & Movahedi, A. (2010). Effects of different variations of mental and physical practice on sport skill learning in adolescents with mental retardation. *Research in Developmental Disabilities, 31* (1), 81-86.

Holmes, P., & Calmels, C. (2008). A neuroscientific review of imagery and observation use in sport. *Journal of Motor Behavior, 40* (5), 433-445.

Holmes, P. S. (2007). Theoretical and practical problems for imagery in stroke rehabilitation: An observation solution. *Rehabilitation Psychology, 52* (1), 1-10.

Holper, L., Scholkmann, F., Shalom, D., & Wolf, M. (2012). Extension of mental preparation positively affects motor imagery as compared to motor execution:

A functional near-infrared spectroscopy study. *Cortex, 48,* 593-603.

Hong, I. K., Choi, J. B., & Lee, J. H. (2012). Cortical changes after mental imagery training combined with electromyography-triggered electrical stimulation in patients with chronic stroke. *Stroke, 43* (9), 2506-2509.

Hussey E. P., Smolinsky, J. G., Piryatinsky, I., Budson, A. E., & Ally, B. A. (2012). Using mental imagery to improve memory in patients with Alzheimer disease: Trouble generating or remembering the mind's eye? *Alzheimer Disease and Associated Disorders, 26* (2), 124-134.

Iachini, T. (2002). Spazio, movimento e immagini mentali. In A. M. Borghi and T. Iachini (eds) *Scienze della mente* (176-184). Bologna: Il Mulino.

Iachini, T. (2011). Mental imagery and embodied cognition: A multimodal approach. *Journal of Mental Imagery, 35* (3-4), 1-28.

Iacoboni, M., Woods, R. P., Brass, M., Bekkering, H., Mazziotta, J. C., & Rizzolatti, G. (1999). Cortical mechanisms of human imitation. *Science, 286,* 2526-2528.

Ishai, A., Ungerleider, L. G., & Haxby, G. V. (2000). Distributed neural systems for the generation of visual images. *Neuron, 28,* 379-390.

Jackson, P. L., Lafleur, M. F., Malouin, F., Richards, C. L., & Doyon, J. (2003). Functional cerebral reorganization following motor sequence learning through mental practice with motor imagery. *Neuroimage, 20* (2), 1171-1180.

Jackson, P. L., Lafleur, M. F., Malouin, F., Richards, C., & Doyon, J. (2001). Potential role of mental practice using motor imagery in neurologic rehabilitation. *Archives of Physical Medical Rehabilitation, 82* (8), 1133-1141.

Jeannerod, M. (1994). The representing brain. Neural correlates of motor intention and imagery. B*ehavioral & Brain Sciences, 17,* 187-245.

Jeannerod, M. (1995). Mental imagery in the motor context. *Neuropsychologia, 33* (11), 1419-1432.

Jeannerod, M. (2001). Neural simulation of action: A unifying mechanism for motor cognition. *NeuroImage, 14,* 103-109.

Joffe, V. L., Cain, K., & Marić, N. (2007). Comprehension problems in children with specific language impairment: Does mental imagery training help? *International Journal of Language and Communication Disorders, 42* (6), 648-664.

Johnson-Frey, S. H. (2004). Stimulation through simulation? Motor imagery and functional reorganization in hemiplegic stroke patients. *Brain Cognition, 55* (2), 328-331.

Kalkstein, J., Checksfield, K., Bollinger, J., & Gazzaley, A. (2011). Diminished top-down control underlies a visual imagery deficit in normal aging. *The Journal of Neuroscience, 31* (44), 15768-15774.

Kemps, E., & Newson, R. (2005). Patterns and predictors of adult age differences in mental imagery. *Aging, Neuropsychology, and Cognition, 12* (1), 99-128.

Kosslyn, S. M. (1999). The Role of Area 17 in Visual Imagery: Convergent Evidence from PET and rTMS. *Science, 284*, 167-170.

Kosslyn, S. M. (2005). Mental images and the brain. *Cognitive Neuropsychology, 22,* 333-347.

Kosslyn, S. M., & Dror, I. E. (1992). A cognitive neuroscience of Alzheimer's disease: What can be learned from studies of visual imagery? In Y. Christen and P. Churchland (eds.) *Neurophilosophy and Alzheimer's Disease*. New York: Springer-Verlag.

Kosslyn, S. M., Ganis, G., & Thompson, W. L. (2001). Neural foundation of imagery. *Nature Reviews - Neuroscience, 2*, 635-642.

Kosslyn, S. M., Margolis, J. A., Goldknopf, E. J., Daly, R. F. & Barrett, A. M. (1990). Age differences in imagery abilities. *Child Development, 61,* 995-1010.

Kosslyn, S. M., Thompson, W. L., & Ganis, G. (2006). *The case for mental imagery.* New York: Oxford University Press.

Kosslyn, S. M., Thompson, W. L., Shephard, J. M., Ganis, G., Bell, D., Danovitch, J. et al. (2004). Brain rCBF and performance in visual imagery tasks: Common and distinct processes. *European Journal of Cognitive Psychology, 16* (5), 696-716.

Kranczioch, C., Zich, C., Schierholz, I., & Sterr, A. (2014). Mobile EEG and its potential to promote the theory and application of imagery-based motor rehabilitation. *International Journal of Psychophysiology, 91* (1), 10-15.

Lebrato, M. T. & Ellis, N. R. (1974). Imagery mediation in paired associate learning by retarded and nonretarded subjects. *American Journal of Mental Deficiency, 78* (6), 704-713.

Lee, G., Song, C., Lee, Y., Cho, H., & Lee, S. (2011). Effects of motor imagery training on gait ability of patients with chronic stroke. *Journal of Physical Therapy Science, 23* (2), 197-200.

Leifert-Fiebach, G., Welfringer, A., Babinsky, R., & Brandt, T. (2013). Motor imagery training in patients with chronic neglect: A pilot study. *NeuroRehabilitation, 32* (1), 43-58.

Lidor, R. (2007). Preparatory routines in self-paced events: Do they benefit the skilled athletes? Can they help the beginners? In C. Tenenbaum & R. C. Eklund (Eds.), *Handbook of Sport Psychology* (pp. 445-465). New York: Wiley.

Liu, K. P., Chan, C. C., Lee, T. M., & Hui-Chan, C. W. (2004). Mental imagery for promoting relearning for people after stroke: A randomized controlled trial. *Archives of Physical Medicine and Rehabilitation, 85* (9), 1403-1408.

Malouin, F., & Richards, C. L. (2010). Mental practice for relearning locomotor skills. *Physical Therapy, 90*, 240-251.

Malouin, F., Richards, C. L., & Durand, A. (2010). Normal aging and motor imagery vividness: implications for mental practice training in rehabilitation. *Archives of Physical Medicine and Rehabilitation, 91* (7), 1122-1127.

Martin, K. A., Moritz, S. E., & Hall, C. R. (1999). Imagery use in sport: A literature review and applied model. *The Sport Psychologist, 13*, 245-268.

Mason, S. E., & Smith, A. D. (1977). Imagery in the aged. *Experimental Aging Research, 3,* 17-32.

May, J., Calvo-Merino, B., Delahunta, S., McGregor, W., Cusack , R., Owen, A., Veldsman, M., Ramponi, C., & Barnard, P. (2011). Points in mental space:

an interdisciplinary study of imagery in movement creation. *Dance Research, 29* (2), 402-430.

McAvinue, L. P., & Robertson I. H. (2011). Individual differences in response to phantom limb movement therapy. *Disability and Rehabilitation, 33*, 2186-2195.

McCarthy, M., Graham Beaumont, J., Thompson, R., & Pringle, H. (2002). The role of imagery in the rehabilitation of neglect in severely disabled brain-injured adults. *Archives of Clinical Neuropsychology, 17* (5), 407-422.

Milne, M., Hall, C., & Farwell, L. (2005). Self-efficacy, imagery use, and adherence to rehabilitation by injured athletes. *Journal of Sport Rehabilitation, 14* (2), 150-167.

Monsma, E., Mensch, J., & Farroll, J. (2009). Keeping your head in the game: Sport-specific imagery and anxiety among injured athletes. *Journal of Athletic Training, 44* (4), 410-417.

Moran, A. (1993). Conceptual and methodological issues in the measurement of mental imagery skills in athletes. *Journal of Sport Behavior, 16,* 156-170.

Morganti, F., Gaggioli, A., Castelnuovo, G., Bulla, D., Vettorello, M., & Riva, G. (2003). The use of technology-supported mental imagery in neurological rehabilitation: A research protocol. *Cyberpsychology and Behavior, 6* (4), 421-427.

Morris, T., Spittle, M., & Watt, A. P. (2005). *Imagery in sport*. Minnesota: Human Kinetics.

Moulton, S. T., & Kosslyn, S. M. (2009). Imagining predictions: mental imagery as mental emulation. Philosophical Transactions of the Royal Society of London, Series B: *Biological Sciences, 364,* 1273-1280.

Mulder, T. (2007). Motor imagery and action observation: cognitive tools for rehabilitation. *Journal of Neural Transmission, 114* (10), 1265-1278.

Munzert, J., Lorey B., & Zentgraf, K. (2009). Cognitive motor processes: the role of motor imagery in the study of motor representations. *Brain Research Reviews, 60,* 306-326.

Murphy, S. M., & Martin K. A. (2002). The use of imagery in sport. In T.S. Horn (Ed.), *Advances in sport psychology* (pp. 405-4399). Champaign, IL: Human Kinetics.

Murphy, S. M. (1994). Imagery interventions in sport. *Medicine & Science in Sports & Exercise, 26,* 486-494.

Nideffer, R. M. (1985). *Athletes' guide to mental training*. Minnesota: Human Kinetics.

Nilsen, D., Gillen, G., & Gordon, A. (2010). Use of Mental Practice to Improve Upper-Limb Recovery After Stroke: A Systematic Review. *American Journal of Occupational Therapy, 64* (5), 695-708.

Nyberg, L. Eriksson, J., Larsson, A., & Marklund, P. (2006). Learning by doing versus learning by thinking: an fMRI study of motor and mental training. *Neuropsychologia, 44,* 711-717.

Oliverio, A. (2013). *Immaginazione e memoria. Fantasia e realtà nei processi mentali*. Milano: Mondadori.

Olsson, C. J., Jonsson, B., Nyberg, L. (2008). Learning by doing and learning by thinking: An FMRI study of combining motor and mental training. *Frontiers Human Neuroscience, 2,* 5-13.

Orgs, G., Dombrowski, J. H., Heil, M., & Jansen-Osmann, P. (2008). Expertise in dance modulates alpha/beta event-related desynchronization during action observation. *European Journal of Neuroscience, 27* (12), 3380-3384.

Ortner, R., Irimia, D. C., Scharinger, J., & Guger, C. (2012). A motor imagery based brain-computer interface for stroke rehabilitation. *Studies in health technology and informatics, 181*, 319-323.

Page, S. J., Levine, P., & Leonard, A. (2007). Mental practice in chronic stroke: results of a randomized, placebo-controlled trial. *Stroke, 38* (4), 1293-1297.

Palladino, P., & De Beni, R. (2003). When mental images are very detailed: image generation and memory performance as a function of age. *Acta Psychologica, 113* (3), 297-314.

Papadelis, C., Kourtidou-Papadeli, C., Bamidis, P., & Albani, M. (2007). Effects of imagery training on cognitive performance and use of physiological measures as an assessment tool of mental effort. *Brain and Cognition, 64* (1), 74-85.

Pearson, D., De Beni, R., & Cornoldi, C. (2001). The generation, maintenance, and transformation of visuo-spatial mental images. In M. Denis, R. H. Logie, C. Cornoldi, M. De Vega, & J. Engelkamp (Eds.). *Imagery, Language and Visuo-Spatial Thinking* (pp. 1-27). Hove, UK: Psychology Press.

Porretta, D. L., & Surburg, P. R. (1995). Imagery and physical practice in the acquisition of gross motor timing of coincidence by adolescents with mild mental retardation. *Perceptual and Motor Skills, 80*, 1171-1183.

Prasad, G., Herman, P., Coyle, D., McDonough, S., & Crosbie, J. (2009). Using motor imagery based brain-computer interface for post-stroke rehabilitation. In *Proceedings of the 4th International IEEE/EMBS Conference on Neural Engineering,* 258-262.

Reeds, C. L. (2002). Chronometric comparisons of imagery to action: Visualizing versus physically performing springboard dives. *Memory and Cognition, 30* (8), 1169–1178.

Rienzo, F. D., Guillot, A., Rode, G., & Collet, C. (2012). Therapeutic relevance of motor imagery in motor rehabilitation after spinal cord injury. *Spinal Cord Injuries: Causes, Risk Factors and Management,* 203-218.

Roosink, M., & Zijdewind, I. (2010). Corticospinal excitability during observation and imagery of simple and complex hand tasks: Implications for motor rehabilitation. *Behavioural Brain Research, 213* (1), 35-41.

Roskos-Ewoldsen, B., Conners, F. A., Atwell, J. A., & Prestopnik, J. L. (2006). Visual imagery scanning in young adults with intellectual disability. *American Journal on Mental Retardation, 111* (1), 35-47.

Roskos-Ewoldsen, B., Intons-Peterson, M. J., & Anderson, R. E. (Eds) (1993). *Imagery, creativity, and discovery: A cognitive perspective*. Amsterdam: North-Holland/Elsevier Science Publishers.

Sala, J. B., Rama, P., & Courtney, S. M. (2003). Functional topography of a distributed neural system for spatial and nonspatial information maintenance in working. *Neuropsychologia, 41,* 341-356.

Schack, T., & Ritter, H. (2009). The cognitive nature of action – functional links between cognitive psychology, movement science and robotics. In M. Raab, J. Johnson, & H. Heukeren (Eds.), *Progress in brain research: Mind and motion – The bidirectional link between thought and action* (pp. 231-252). Amsterdam: Elsevier.

Schack, T., & Ritter, H. (2013). Representation and learning in motor action – Bridges between experimental research and cognitive robotics. *New Ideas in Psychology, 31* (3), 258-269.

Schott, N. (2012). Age-related differences in motor imagery: Working memory as a mediator. *Experimental Aging Research, 38* (5), 559-583.

Schuster, C., Hilfiker, R., Amft, O., Scheidhauer, A., Andrews, B., Butler, J., Kischka, U., & Ettlin, T. (2011). Best practice for motor imagery: A systematic literature review on motor imagery training elements in five different disciplines. *BMC Medicine, 9,* 75.

Sergent, J. (1990). The neuropsychology of visual image generation: data, method, and theory. *Brain and Cognition, 13,* 98-129.

Sharma, N., Pomeroy, V. M., & Baron, J. C. (2006). Motor imagery: a backdoor to the motor system after stroke? *Stroke, 37,* 1941-1952.

Sheikh, A. A., Sheikh, K. S., & Moleski, L. M. (1994). Improving imaging abilities. In Sheikh and Korn (Ed.), *Imagery in sports and physical performance*. Baywood Publishing Company.

Skoura, X., Papaxanthis, C., Vinter, A., & Pozzo, T. (2005). Mentally represented motor actions in normal aging: I. Age effects on the temporal features of overt and covert execution of actions. *Behavioural Brain Research, 165*, 229-239.

Slotnick, S. D., Thompson, W. L., & Kosslyn, S. M. (2012). Visual memory and visual mental imagery recruit common control and sensory regions of the brain. *Cognitive Neuroscience, 3* (1), 14-20.

Smania, N., Bazoli, F., Piva, D., & Guidetti, G. (1997). Visuomotor imagery and rehabilitation of neglect. *Archives of Physical Medicine and Rehabilitation, 78* (4), 430-436.

Smith, D., Holmes, P., Whitemore, L., Collins, D., & Devonport, T. (2001). The effect of theoretically-based imagery scripts on field hockey performance. *Journal of Sport Behavior, 24,* 408-419.

Sordoni, C., Hall, C., & Forwell, L. (2000). The use of imagery by athletes during injury rehabilitation. *Journal of Sport Rehabilitation, 9* (4), 329-338.

Steenbergen, B., Crajé, C., Nilsen, D. M., & Gordon, A. M. (2009). Motor imagery training in hemiplegic cerebral palsy: A potentially useful therapeutic tool for rehabilitation. *Developmental Medicine and Child Neurology, 51* (9), 690-696.

Steenbergen, B., Jongbloed-Pereboom, M., Spruijt, S., & Gordon, A. M. (2013). Impaired motor planning and motor imagery in children with unilateral spastic cerebral palsy: Challenges for the future of paediatric rehabilitation, *Developmental Medicine and Child Neurology, 55* (suppl.4), 43-46.

Surburg, P. R. (1991). Preparation process facilitation of a motor task through imagery practice with adolescents who have mental retardation. *American Journal of Mental Deficiency, 95*, 428-434.

Surburg, P. R., Porretta, D. L., & Sutlive, V. (1995). Use of imagery practice for improving a motor skill. *Adapted Physical Activity Quarterly, 12* (3), 217-227.

Symmes, J. S. (1971). Visual imagery in brain-injured children. *Perceptual and Motor Skills, 33* (2), 507-514.

Szameitat, A. J., Shen, S., & Sterr, A. (2007). Motor imagery of complex everyday movements, An fMRI study. *Neuroimage, 34,* 702-713.

Taktek, K. (2004). The effects of mental imagery on the acquisition of motor skills and performance: A literature review with theoretical implications. *Journal of Mental Imagery, 28* (1-2), 79-114.

Thompson, W. L., & Kosslyn, S. M. (2000). Neural systems activated during visual mental imagery: A review and meta-analyses. In Toga, A. W., Mazziotta, J. C. (eds) *Brain Mapping: The Systems* (pp. 535-560). San Diego: Academic Press.

Thompson, W. L., Slotnick, S. D., Burrage, M. S., & Kosslyn, S. M. (2009). Two forms of spatial imagery: Neuroimaging evidence. *Psychological Science, 20* (10), 1245–1253.

Tippett, L. J. (1992). The generation of mental images: a review of neuropsychological research and theory. *Psychological Bulletin, 112,* 415-432.

Trojano, L., Conson, M., Maffei, R., & Grossi, D. (2006). Categorical and coordinate spatial processing in the imagery domain investigated by rTMS. *Neuropsychologia, 44* (9), 1569-1574.

Vealey, S., & Greenleaf, C. A. (2006). Seeing is believing: Understanding and using imagery in sport. In J M Williams (Ed.), *Applied sport psychology: Personal growth to peak performance*. San Francisco, CA: Mayfield.

Velentzas, K., Heinen, T., Tenenbaum, G. & Schack, T. (2010). Functional Mental Representation of Volleyball Routines in German Youth Female National Players. *Journal of Applied Sport Psychology, 22* (4), 474-485.

Vicari, S., Bellucci, S., & Carlesimo, G. A. (2006). Evidence from two genetic syndromes for the independence of spatial and visual working memory. *Developmental Medicine and Child Neurology, 48* (2), 126-131.

Wei, G., & Luo, J. (2010). Sport expert's motor imagery: Functional imaging of professional motor skills and simple motor skills. *Brain Research, 1341,* 52-62.

Welfringer, A., Leifert-Fiebach, G., Babinsky, R., & Brandt, T. (2011). Visuomotor imagery as a new tool in the rehabilitation of neglect: A randomised controlled study of feasibility and efficacy. *Disability and Rehabilitation, 33* (21-22), 2033-2043.

Wesch, N., Hall, C., Prapavessis, H., Maddison, R., Bassett, S., Foley, L., Brooks, S., & Forwell, L. (2012). Self-efficacy, imagery use, and adherence during injury rehabilitation. *Scandinavian Journal of Medicine and Science in Sports, 22* (5), 695-703.

Wondrusch, C., & Schuster-Amft, C. (2013) A standardized motor imagery introduction program (MIIP) for neuro-rehabilitation: Development and evaluation. *Frontiers in Human Neuroscience, 7,* 477.

Wuyam, B., Moosavi, S. H., Decety, J., Adams, L., Lansing, R. W., & Guz, A. (1995). Imagination of dynamic exercise produced ventilatory responses which were more apparent in competitive sportsmen. *Journal of Physiology, 482,* 713-724.

Yarrow, K., Brown, P., & Krakauer, J. W. (2009). Inside the brain of an elite athlete: the neural processes that support high achievement in sports. *Nature Reviews Neuroscience, 10* (8), 585-96.

Zapparoli, L., Invernizzi, P., Gandola, M., Verardi, M., Berlingeri, M., Sberna, M., De Santis, A., & Paulesu E. (2013). Mental images across the adult lifespan: A behavioural and fMRI investigation of motor execution and motor imagery. *Experimental Brain Research, 224* (4), 519-540.

Zehnder, F., Martin, M., Altgassen, M., & Clare, L. (2009). Memory training effects in old age as markers of plasticity: A meta-analysis. *Restorative Neurology and Neuroscience, 27* (5), 507-520.

Zeman, A. Z. J., Della Sala, S., Torrens, L. A., Gountouna, V. E., McGonigle, D. J., & Logie, R. H. (2010). Loss of imagery phenomenology with intact visuo-spatial task performance: A case of 'blind imagination'. *Neuropsychologia, 48*, 145-155.

Zhang, H., Xu, L., Wang, S., Xie, B., Guo, J., Long, Z., & Yao, L. (2011). Behavioral improvements and brain functional alterations by motor imagery training. *Brain Research, 1407*, 38-46.

Ziemke, T., Jirenhed, D. A., & Hesslow, G. (2005). Internal simulation of perception: a minimal neuro-robotic model. *Neurocomputing, 68*, 85-104.

Zimmermann-Schlatter, A., Schuster, C., Puhan, M. A., Siekierka, E., & Steurer, J. (2008). Efficacy of motor imagery in post-stroke rehabilitation: A systematic review. *Journal of NeuroEngineering and Rehabilitation, 5*, 8.

Zupnick, J. J., & Meyer, P. A. (1975). Long-term effectiveness of imagery instructions with retarded persons. *American Journal of Mental Deficiency, 79,* 519-525.