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# Mental Representation for Action in the Elderly: Implications for Movement Efficiency and Injury Risk

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## Abstract

Recent research findings indicate that with older adulthood, there are functional decrements in spatial cognition and more specially, in the ability to mentally represent and effectively plan motor actions. A typical finding is a significant over- or underestimation of one's actual physical abilities with movement planning—planning that has implications for movement efficiency and physical safety. A practical, daily life example is estimation of reachability—a situation that for the elderly may be linked with fall incidence. A strategy used to mentally represent action is the use of motor imagery—an ability that also declines with advancing older age. This brief review highlights research findings on mental representation and motor imagery in the elderly and addresses the implications for improving movement efficiency and lowering the risk of movement-related injury.

## Keywords

aging, mental representation, mental imagery, motor imagery, action planning

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## Introduction

With aging into older adulthood, several cognitive and neurological deficits can influence daily living activities and risk for physical injury. Among the decrements evidenced in the elderly is a general functional decline in spatial cognition (Klenchlen, Després, & Durfour, 2012), more specifically, the ability to mentally represent and effectively plan motor actions. Effective motor planning underscores movement efficiency and enjoyment, and lowers injury risk. This brief review article highlights contemporary literature regarding the ability to mentally represent action in the elderly. In addition to the description of prominent terms and insightful experimental research, this piece provides implications for clinical practice and everyday consideration in helping the elderly plan motor actions. Underscoring the significance of this paper is the fact that there is a critical need to better understand the factors that constrain the elderly in regard to mentally representing and planning movements. With that understanding, we can develop strategies for improvement of performance. With the development of such strategies, the quality of life could be enhanced for a segment of the population that is growing in proportion to the whole U.S. nation.

## Mental (Action) Representation and Motor Imagery (MI)

### *Mental Representation*

The nature of mental representation is a central issue for understanding cognitive and motor behavior across the life span. In general, the term is used as a construct of neuro- and cognitive science involving cognitive states and processes constituted by the occurrence, transformation, and storage of information-bearing structures (representations) of one kind or another (Stanford Encyclopedia of Philosophy, 2008). From another perspective, it is an internal cognitive construct that represents external reality. As presented here, imagery is a form of and key modality for the creation of representations (see review by Kosslyn, Thompson, & Ganis, 2006)—more specifically, the creation of representations involving action in the context of movement planning and subsequent execution, that is, action representation (e.g., Choudhury, Charman, Bird, & Blakemore, 2007; Gabbard, 2009; Helbig, Graf, & Kiefer, 2006).

Motor programming theory in general suggests that an integral component in an effective outcome is an adequate action representation of the movements. This view contends that action representation is a key feature of an internal forward model, which is a neural system that simulates the dynamic behavior of the body in relation to the environment (Penhune & Steele, 2012; Schubotz, 2007; Wolpert, 1997). This theory proposes that internal models make predictions (estimates) about the mapping of the self to parameters of the external world—processes that enable successful planning and execution of action. These representations are hypothesized to be an integral part of action planning. Complementing the forward model idea and central to the present discussion is the widely acknowledged proposition that simulation in the form of *MI provides a window into the process of action representation*, that is, it reflects an internal action representation (Chabeauti, Assaiante, & Vaugoyeau, 2012; Jeannerod, 2001; Munzert, Lorey, & Zentgraf, 2009; Wintermute, 2012).

## MI

MI is defined as an internal rehearsal or reenactment of movements from a first-person perspective without any overt physical movement. From another perspective, MI, also known as kinesthetic imagery, is an active cognitive process during which the representation of a specific action is internally reproduced in working memory without any overt motor output (Decety & Grezes, 1999). In addition to the reasonable case that MI is a reflection of action representation and motor planning, studies have found that there is a high correlation between real and simulated movements (e.g., Burianová et al., 2013; Kunz, Creem-Regehr, & Thompson, 2009; Lorey et al., 2009). Furthermore, evidence has been reported showing that MI follows the basic tenets of Fitts's Law (Solodkin, Hlustik, Chen, & Small, 2004; Stevens, 2005)—that is, simulated movement duration like actual movement decreases with increasing task complexity. As opposed to visual imagery, defined as the internal enactment or reenactment of perceptual experiences (Barsalou, 2008), neuroimaging and neuropsychological studies indicate that MI is more affected by biomechanical (kinesthetic) constraints that are commonly associated with action processing (see review by Pelgrims, Andres, & Olivier, 2005; Stevens, 2005).

One of prominent features of MI is its role in the prediction of one's actions (e.g., Kunz et al., 2009; Lorey et al., 2009). One of the important aspects of an action plan is the ability to predict the outcome and consequences of intended actions. Suddendorf and Moore (2011) noted, "the ability to imagine future events is an essential part of human cognition" (p. 295). Imagery allows us to generate specific predictions based on past experience and allows us to answer "what if" questions by making explicit and accessible the likely consequences of a specific action. Imagining an action can serve several useful goals to that endeavor. According to Bourgeois and Coello (2009), motor representation can be viewed as a component of a predictive system, including a neural process that simulates through MI the dynamic behavior of the body in relation to the environment.

## Mental Representation in the Elderly

Recent observations indicate that the ability to mentally represent motor actions declines with advancing age (>64 years; Beauchet et al., 2010; Caçola, Roberson, & Gabbard, 2013; Mulder, Hochstenbach, Heuvelena, & Otter, 2008; Personnier, Bally, & Papaxanthis, 2010; Saimpont, Mourey, Manckoundia, Pfitzenmeyer, & Pozzo, 2010; Skoura, Personnier, Vinter, Pozzo, & Papaxanthis, 2008; Zapparoli et al., 2013). For example, while examining the relation between vividness of movement imagery via questionnaire, Mulder and colleagues (2008) found that older adults were slightly worse than their younger counterparts, especially from a first-person perspective. A possible link between level of physical activity and imagery ability was suggested but not tested. The assertion was that physical exercise in the elderly might help preserve brain structures and mechanisms (frequently mentioned is the parietal cortex) associated with mental representation. Using a mental chronometry paradigm comparing imagined and executed arm pointing actions between young and older adults, Personnier et al. (2010) found that although older adults used efferent copies of motor commands to generate motor representations (i.e., they displayed the ability to mentally represent action), this ability progressively deteriorated with advancing age as evidenced by the declining quality of their MI (i.e., isochrony between executed and imagined movements). The authors concluded that there was a likelihood of weakness in the formulation of internal models of action in the elderly. Testing the ability to mentally simulate/plan a complex sequential action of the whole body (i.e., rising from the floor), Saimpont and colleagues (2010) reported that the elderly experienced significant difficulties compared with young adults' accuracy in action sequence and reaction time.

In a more recent review of this body of research pertaining to individuals 55 years and older, Saimpont, Malouin, Tousignant, and Jackson (2013) concluded that MI accuracy for simple/usual upper-limb movements appears well preserved with aging, whereas there appears to be an aging effect with upper-limb actions with unusual biomechanical constraints and, with relevance to the next topic of discussion, with actions requiring the integration.

### *Estimation of Reach*

Estimation of whether an object is reachable or not from a specific body position constitutes an important aspect in effective motor planning—a situation that has scientific and real-world implications. That estimation is based in large part on the individual's ability to mentally represent the desired action and a function of perceived body capabilities. An experimental tactic that provides insight into this phase of motor planning (estimation) is the estimation of reach via use of MI. That methodology has drawn the interest of contemporary researchers for examining the processes involved in action representation (Coello et al., 2008; Coello & Delevoye-Turrell, 2007; Lamm, Fischer, & Decety, 2007). Estimation of reach complements the internal modeling notion of "can I do this?" and "what are the consequences?" which arguably, are relevant questions in planning movements (Wolpert, 1997). More specific to reach, one of the initial steps in programming such movements is to derive a perceptual estimate of the object's distance and location relative to the body. This means that an individual must be able to perceive critical reach distances beyond which a particular reach action is no longer afforded and to which a transition to another reach mode must occur. For example, is the object close enough to reach while seated, or do I need to stand? Furthermore, with older persons, could I lose balance and fall? Such questions are not uncommon in everyday situations—for example, reaching for an object on a table or reaching and grasping a hand rail.

Using the estimation of reach paradigm, Gabbard, Caçola, and Cordova (2011) reported that younger adults (*M* age = 20 years) were significantly more accurate than older adults (*M* age = 77 years) when estimating reach in peripersonal and extrapersonal space from a seating position. Whereas both groups made more errors in extrapersonal space, the values were significantly higher for the older group, that is, they overestimated to a greater extent. In 2012, Caçola, Martinez, and Ray reported that accuracy decreased as age increased when estimating reachability in peripersonal and extrapersonal space using a 40-cm tool; the population ranged from 55 to 92 years. To summarize, it would appear that older persons have difficulty estimating possible movement outcomes and updating internal models, which results in a dissociation between perception and action—a condition that may promote risky motor planning.

One example of daily living "actual" reach with implications for physical safety is functional reach. Commonly used when assessing the elderly, functional reach is the maximal distance an individual is capable of reaching forward while standing, without taking a step or losing balance. It is described as a dynamic measure of postural control. The literature supports the observation that with advancing age, there is a sharp decline in functional reach (Costarella, Monteleone, Steindler, & Zuccaro, 2010; Zuccaro, Steindler, Scena, & Costarella, 2012). And, perhaps most relevant to the considerations of safety, research also indicates a significant relationship between functional reach and the risk of falling (Duncan, Weiner, Chandler, & Studenski, 1990; Huang, Gau, Chuan, & Kernohan, 2003). In a recent study of young adults (*M* age = 22 years) and older adults (66 years) examining the relationship between estimation of reach and functional reach, Gabbard and Cordova (2013) reported that only the younger group showed a significant association between the two variables. In other words, the congruence between movement planning (estimation) and execution was significantly better with the younger group.

## Implications and Applications

As noted in the "Introduction" section, there is a critical need to better understand the factors that constrain the elderly in regard to mentally representing and planning movements. Such an understanding may lead clinicians to develop strategies and training protocols that help maintain or even improve performance—behavior that enhances movement efficiency and lowers associated injury risk. In regard to injury risk is the higher likelihood, compared with younger adults, of falling during reach actions. For example, if an older adult either significantly underestimates or overestimates a reach target (e.g., drinking glass, table, railing), he or she may have more difficulty than a younger person in maintaining postural control resulting in a fall. According to a view of the latest CDC website, "each year, one in every three adults age 65 and older falls." "Among older adults (those 65 or older), falls are the leading cause of injury death." In partial support of the reach–fall link, 4 of the 16 items on the activities-specific balance confidence (ABC) scale (Powell & Myers, 1995) are reach-specific questions. That test is commonly cited as a self-report subjective measure of perceived balance confidence in performing various movement activities without falling.

One, if not the most, evident finding associated with MI is its potential as a therapeutic tool. The use of MI has been documented as an effective training and therapy tool for sport or motor performance (Gentili, Han, Schweighofer, & Papaxanthis, 2010; Guillot, Tolleron, & Collet, 2010; Lebon, Collet, & Guillot, 2010; Zhang et al., 2011), brain injury (Osstra, Vereecke, Jones, Vanderstraeten, & Vingerhoets, 2012), stroke (Hosseini, Fallahpour, Syadi, Gharib, & Haghgoo, 2012; see reviews by Malouin & Richards, 2010; Sharma et al., 2009), and other neuromotor impairments (Heremans et al., 2012). For motor performance, studies commonly suggest that imagery training facilitates motor learning processes and improves motor performance. In the context of neurological impairment, the literature suggests that one of the key agents in movement recovery is the use of MI to stimulate the otherwise nonactive or impaired neural pathways. In addition, Wohldmann, Healy, and Bourne (2008) reported evidence to support the hypothesis that mental practice strengthens abstract mental representation that does not involve specific effectors—that is, such practice strengthens "central" features of the representation as well as the representation of specific body part processes. To examine the hypothesis, the researchers had participants type four-digit numbers in a familiarization phase, training phase (using imagined and actual execution with a different digit configuration or the opposite hand), and delay condition (actual execution using same setup as the familiarization); the fingers represented specific movement effectors.

It is also important to note that of either visual or motor (kinesthetic) imagery, MI, as proposed here, has shown to be more effective in cortiomotor stimulation (e.g., Stinear, Byblow, Steyvers, Levin, & Swinnen, 2006; Voisin, Mercier, Jackson, Richards, & Malouin, 2011).

Whereas the information on clinical strategies to improve mental imagery among the elderly is sparse, information derived from training studies among brain and stroke patients may be applicable (e.g., Langhome, Coupar, & Pollock, 2009; Schuster et al., 2011). Those strategies include

1. *first-person internalizing*—that is, focus on the self as the mental image of the intended action. This state is the first component in the actor–object dyad. Part of this dyad is an understanding of one's physical capabilities and potential consequences. Ask the participant to consider the consequences if he or she were to miss-plan (over- or underestimate) the event. What will you fall into? Do you feel confident in your ability to gain stability if you have to adjust your position quickly?
2. *focalization on the effector*—this is, the specific part of the self that is linked with the target. For example, the arm/hand when intending to reach and grasp an object.
3. *focus on the visual cues* (target/object/goal). The end point of the intended action — the target. For example, where does my hand need to be to grasp the object securely.
4. *reinforcement on kinesthetically "feeling" execution of movement.* Research indicates clearly that "feeling" rather than just seeing oneself perform the action promotes a better mental representation for movement via internalization.
5. *combine physical with mental practice*. By practicing actual movements, participants gain a better understanding of their physical capabilities and develop movement endurance—a problem that is common in the elderly. Mental practice affords the opportunity to test one's capabilities. Furthermore, research shows that mental practice combined with physical practice enhances actual performance outcome (Reiser, Busch, & Munzert, 2011; Schuster et al., 2011).

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## References

Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology*, *59*, 617-645.

Beauchet, O., Annweiler, C., Assal, F., Bridenbaugh, S., Hermann, R. R., Kressig, R. W., & Allali, G. (2010). Imagined Timed Up & Go test: A new tool to assess higher-level gait and balance disorders in older adults? *Journal of Neurological Sciences*, *294*, 102-106.

Bourgeois, J., & Coello, Y. (2009). Role of inertial properties of the upper limb on the perception of the boundary of personal space. *Psychologie Française*, *54*, 225-239.

Burianová, H., Marstaller, L., Sowman, P., Tesan, G., Rich, A. N., Williams, M., & Johnson, B.W. (2013). Multimodal functional imaging of motor imagery using a novel paradigm. *NeuroImage*, *71*, 50-58.

Caçola, P., Martinez, A., & Ray, C. (2012). The ability to modulate peripersonal and extrapersonal reach space via tool use among the elderly. *Archives of Gerontology and Geriatrics*, *56*, 383-388.

Caçola, P., Roberson, J., & Gabbard, C. (2013). Aging in movement representations for sequential finger movements: A comparison between young, middle-aged, and older adults. *Brain and Cognition*, *82*, 1-5.

Chabeauti, P. Y., Assaiante, C., & Vaugoyeau, M. (2012). Extreme short-term environmental constraints do not update internal models of action as assessed from motor imagery in adults. *Neuroscience*, *222*, 69-74.

Choudhury, S., Charman, T., Bird, V., & Blakemore, S. (2007). Development of action representation during adolescence. *Neuropsychologia*, *45*, 255-262.

Coello, Y., Bartolo, A., Amiri, B., Devanne, H., Houdayer, E., & Derambure, P. (2008). Perceiving what is reachable depends on motor representations: Evidence from transcranial magnetic stimulation study. *PLoS ONE*, *3*(8), e2862.

Coello, Y., & Delevoye-Turrell, Y. (2007). Embodiment, spatial categorization and action. *Consciousness and Cognition*, *16*, 667-683.

Costarella, M., Monteleone, L., Steindler, R., & Zuccaro, S. M. (2010). Decline of physical and cognitive conditions in the elderly measured through the functional reach test and the mini-mental state examination. *Archives of Gerontology and Geriatrics*, *50*, 332-337.

Decety, J., & Grezes, J. (1999). Neural mechanisms subserving the perception of human actions. *Trends in Cognitive Sciences*, *3*, 172-178.

Duncan, P. W., Weiner, D. K., Chandler, J., & Studenski, S. (1990). Functional reach: A new clinical measure of balance. *Journal of Gerontology*, *45*(6), M192-M197.

Gabbard, C. (2009). Studying action representation in children via motor imagery. *Brain and Cognition*, *71*, 234-239.

Gabbard, C., Cacola, P., & Cordova, A. (2011). Is there an advanced aging effect on the ability to mentally represent action? *Archives of Geronology and Geriatrics*, *53*, 206-209.

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

Gentili, R., Han, C. E., Schweighofer, N., & Papaxanthis, C. (2010). Motor learning without doing: Trial-by-trial improvement in motor performance during mental training. *Journal of Neurophysiology*, *104*, 774-783. doi:10.1152/jn.00257.2010

Guillot, A., Tolleron, C., & Collet, C. (2010). Does motor imagery enhance stretching and flexibility? *Journal of Sports Sciences*, *28*, 291-298.

Helbig, H. B., Graf, M., & Kiefer, M. (2006). The role of action representation in visual object recognition. *Experimental Brain Research*, *174*, 221-228.

Heremans, E., Nieuwboer, A., Spildooren, J., De Bondt, S., D'Hooge, A. M., Helsen, W., & Feys, P. (2012). Cued motor imagery in patients with multiple sclerosis. *Neuroscience*, *206*, 115-121. Retrieved from http://dx.doi.org/10.1016/j.neuroscience.2011.12.060

Hosseini, S. A., Fallahpour, M., Syadi, M., Gharib, M., & Haghgoo, H. (2012). The impact of mental practice on stroke patient's postural balance. *Journal of the Neurological Sciences*. doi:org/10.1016/j.jns.2012.07.030.

Huang, H., Gau, M., Chuan, W., & Kernohan, G. (2003). Assessing risk of falling in older adults. *Public Health Nursing*, *20*, 99-411.

Jeannerod, M. (2001). Neural simulation of action: A unifying mechanism for motor cognition. *Neuroimage*, *14*, S103-S109.

Klenchlen, G., Després, O., & Durfour, A. (2012). What do we know about aging and spatial cognition? Reviews and perspectives. *Ageing Research Reviews*, *11*, 123-135.

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

Kunz, B. R., Creem-Regehr, S. H., & Thompson, W. B. (2009). Evidence for motor simulation in imagined locomotion. *Journal of Experimental Psychology: Human Perception and Performance*, *35*, 1458-1471.

Lamm, C., Fischer, M. H., & Decety, J. (2007). Predicting the actions of others taps into one's own somatosensory representations—A functional MRI study. *Neuropsychologia*, *45*, 2480-2491.

Langhome, P., Coupar, F., & Pollock, A. (2009). Motor recovery after stroke: A systematic review. *Lancet Neurology*, *8*, 741-754.

Lebon, F., Collet, C., & Guillot, A. (2010). Benefits of motor imagery training on muscle strength. *Journal of Strength and Conditioning Research*, *24*, 1680-1687.

Lorey, B., Bischoff, M., Pilgramm, S., Stark, R., Munzert, J., & Zentgraf, K. (2009). The embodied nature of motor imagery: The influence of posture and perspective. *Experimental Brain Research*, *194*, 233-243.

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

Mulder, T., Hochstenbach, J. B. H., Heuvelena, M. J. G., & Otter, A. R. (2008). Motor imagery: The relation between age and imagery capacity. *Human Movement Science*, *26*, 203-211.

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.

Osstra, K. M., Vereecke, A., Jones, K., Vanderstraeten, G., & Vingerhoets, G. (2012). Motor imagery ability in patients with traumatic brain injury. *Archives of Physical Medicine and Rehabilitation*, *93*, 828-833.

Pelgrims, B., Andres, M., & Olivier, E. (2005). Motor imagery while judging object-hand interactions. *NeuroReport*, *16*, 1193-1196.

Penhune, V. B., & Steele, C. J. (2012). Parallel contributions of cerebellar, striatal, and M1 mechanisms to motor sequence learning. *Behavioural Brain Research*, *226*, 579-591.

Personnier, P., Bally, Y., & Papaxanthis, C. (2010). Mentally represented motor actions in normal aging III: Electromyographic features of imagined arm movements. *Behavioural Brain Research*, *206*, 184-190.

Powell, L. E., & Myers, A. M. (1995). The activities-specific balance confidence (ABC) scale. *Journal of Gerontology A: Biological Science Medical Science*, *50A*, M28-M34.

Reiser, M., Busch, D., & Munzert, J. (2011). Strength gains by motor imagery with different ratios of physical to mental practice. *Frontiers in Psychology*, *2*, Article 194.

Saimpont, A., Malouin, F., Tousignant, B., & Jackson, P. (2013). Motor imagery and aging. *Journal of Motor Behavior*, *45*, 21-28.

Saimpont, A., Mourey, F., Manckoundia, P., Pfitzenmeyer, P., & Pozzo, T. (2010). Aging affects the mental simulation/planning of the “rising from the floor” sequence. *Archives in Gerontology and Geriatrics*, *51*, e41-e45.

Schubotz, R. (2007). Prediction of external events with our motor system: Towards a new framework. *Trends in Cognitive Sciences*, *11*, 211-218.

Schuster, C., Hilfiker, R., Amit, O., Scheidhauer, A., Andrews, B., Bulter, J., & 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.

Sharma, N., Simmons, L. H., Jones, P. S., Day, D. J., Carpenter, T. A., Pomeroy, V. M., & Baron, J. (2009). Motor imagery after subcortical stroke: A functional magnetic resonance imaging study. *Stroke*, *40*, 1315-1324. doi:10.1161/STROKEAHA.108.525766

Skoura, X., Personnier, P., Vinter, A., Pozzo, T., & Papaxanthis, C. (2008). Decline in motor prediction in elderly subjects: Right versus left arm differences in mentally simulated motor actions. *Cortex*, *44*, 1271-1278.

Solodkin, A., Hlustik, P., Chen, E. E., & Small, S. L. (2004). Fine modulation in network activation during motor execution and motor imagery. *Cerebral Cortex*, *14*, 1246-1255.

Stanford Encyclopedia of Philosophy. (2008). *Mental representation*. Open access on-line Encyclopedia. Retrieved from http://plato.stanford.edu/entries/mental-representation/

Stevens, J. A. (2005). Interference effects demonstrate distinct roles for visual and motor imagery during the mental representation of human action. *Cognition*, *95*, 329-350.

Stinear, C. M., Byblow, W. D., Steyvers, M., Levin, O., & Swinnen, S. P. (2006). Kinesthetic, but not visual imagery modulates corticomotor excitability. *Experimental Brain Research*, *168*, 157-164.

Suddendorf, T., & Moore, C. (2011). Introduction to the special edition: The development of episodic foresight. *Cognition Development*, *26*, 295-298.

Voisin, J. I. A., Mercier, C., Jackson, P. L., Richards, C. L., & Malouin, F. (2011). Is somatosensory excitiability more affected by the perspective or modality content of motor imagery? *Neuroscience Letters*, *493*, 33-37.

Wintermute, S. (2012). Imagery in cognitive architecture: Representation and control at multiple levels of abstraction. *Cognitive Systems Research*, *19-20*, 1-29.

Wohldmann, E. L., Healy, A. F., & Bourne, L. E. (2008). A mental practice superiority effect: Less retroactive interference and more transfer than physical practice. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *34*, 823-833.

Wolpert, D. M. (1997). Computational approaches to motor control. *Trends in Cognitive Sciences*, *1*, 209-216.

Zapparoli, L., Invernizzi, P., Gandola, M., Verardi, M., Berlingeri, M., Sherna, M., & Paulesu, E. (2013). Mental images across the adult lifespan: A behavioural and fMRI investigation of motor execution and motor imagery. *Experimental Brain Research*. doi:10.1007/s00221-012-3331-1

Zhang, H., Xu, L., Wang, S., Xie, B., Gui, J., Long, Z., & Yao, L. (2011). Behavioral improvements and brain functional alterations by motor imagery training. *Brain*. doi:10.1016/j.brainres.2011.06.038

Zuccaro, S. M., Steindler, R., Scena, S., & Costarella, M. (2012). Changes of psychical and physical conditions in the elderly after a four-year follow-up. *Archives of Gerontology and Geriatrics*, *54*, 72-77.

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