Archives of Gerontology and Geriatrics 90 (2020) 104099

Contents lists available at ScienceDirect

Archives of Gerontology and Geriatrics

journal homepage: www.elsevier.com/locate/archger

The link between language and action in aging

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ARTICLE INFO

Keywords:
action verb processing
aging
action observation
motor simulation
embodiment

ABSTRACT

Objective: Many studies have demonstrated the existence of a link between action verb processing and action. However, little is known about the changes in this relationship with aging.
Method: To assess this point, we compare the performances of younger and older people during a priming task consisting of judging whether an image contains a human after listening to an action verb.
Results: In accordance with previous literature, the results showed that younger people were faster to detect the presence of a human in the image in congruent conditions, namely, when the action verb and the image refer to the same action. However, this effect was not present in older adults' participants.
Conclusion: These findings suggest that the link between action and language decreases with age. We discuss these findings in the context of the embodied view of cognition.

1. Introduction

In connection with the theory of embodied cognition, which postulates that all cognitive functions are rooted in sensorimotor experiences (Barsalou, 1999, 2008), many studies in the last twenty years have focused on the link between action and language (see Fischer & Zwaan, 2008; Jirak et al., 2010; Willems & Hagoort, 2007 for reviews). Overall, regardless of the modality of action considered (i.e., action production, action simulation, action observation), these studies have shown that action and language are based on common mechanisms (e.g., Bidet-Ildei & Toussaint, 2015; Boulenger et al., 2006) including activation of the mirror system (e.g., Tettamanti et al., 2005), a network of brain areas known to activate both when an individual produces an action and when observing the same action produced by others (Iacoboni & Dapretto, 2006).

Interestingly, although many works have studied the link between action and language in younger adults (see Bidet-Ildei et al., 2020, for a review), nothing is known about the evolution of this link with aging. In the literature, language understanding is known to be one of the most preserved cognitive capacities in aging (Shafto & Tyler, 2014; Tyler et al., 1992). Actually, older people are able to automatically access lexical representations and can construct new syntactic and semantic representations in real time construct online new syntactic and semantic representations (Birren et al., 2006). However, to our knowledge, action language understanding has never been specifically studied, and it was the aim of this paper. Given that activation of motor representations would be directly linked to action verb processing (e.g., Aziz-Zadeh et al., 2006), we can suppose that aging could affect action verb understating. Indeed, despite a relative preservation of the mirror neuron system (Farina et al., 2017), several studies have demonstrated that older people have difficulty using motor imagery and motor simulation (Gabbard et al., 2011; Mulder et al., 2007; Personnier, Ballay, et al., 2010; Personnier, Kubicki, et al., 2010; Personnier et al., 2008; Saimpont et al., 2010; Saimpont et al., 2009; Skoura et al., 2005; Skoura et al., 2008), even though these difficulties can vary with the complexity of the task (Saimpont et al., 2013). For example, using a mental chronometry paradigm to compare executed and imagined gait, Personnier, Kubicki et al. (2010) demonstrated that older people systematically overestimated imagined gait in comparison with executed gait, suggesting that motor imagery becomes less accurate with aging. Interestingly, this decrease in motor imagery capacity also appears when the use of motor simulation is implicit. Indeed, using a hand laterality task (Cooper & Shepard, 1975), Saimpont et al. (2009) have shown that the performances of older people declined compared to younger people, suggesting that implicit use of motor simulation is impaired with aging. This effect is very interesting since it has been shown that the involvement of the motor system in action verb processing is linked to an implicit-not an explicit-use of motor simulation (Beauprez & Bidet-Ildei, 2018; Willems et al., 2010).

In the present study, we examined the possible effects of advanced

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https://doi.org/10.1016/j.archger.2020.104099
Received 21 December 2019; Received in revised form 26 April 2020; Accepted 5 May 2020
Available online 22 May 2020

age on the link between action and language. For this, we exposed younger and older participants to a priming task in which a perceptual task implying a human action.followed the listening to an action verb. In younger subjects, this type of protocol has shown that action verb processing leads to an increase in performance concerning the perceptive judgment of an action congruent with that presented in the prime (e.g., Bidet-Ildei et al., 2011). Linked to embodied theories of cognition (Barsalou, 1999, 2008), these results suggest that both action verb processing and action observation lead to the implicit activation of common sensorimotor representations (Beauprez & Bidet-Ildei, 2018). Related to the known difficulty of aging people to use implicit motor representations (Saimpont et al., 2009), we hypothesize that the link between action and language should decrease with age, which should be manifested as a decrease in the facilitation effect observed when the action verb and the perceived action are congruent.

2. Method

2.1. Participants

25 younger (mean age = 20.9 ± 2.8, range = 18-30; 9 females) and 20 older (mean age = 74.1 ± 7.1, range = 65-84; 17 females) subjects participated to the experiment[1] . The younger adults were students from the University of Poitiers. The older adults were recruited through associations or disseminating information about the study. All subjects were in good health, with normal or corrected-to-normal vision and declared no history of motor or neurological disorders by completing a brief questionnaire. Before their inclusion, the older adults subjects have made a French version of the Mini-Mental State Examination (MMSE) (Folstein et al., 1975) to assess global cognitive function. None of the participants had cognitive impairment (mean score = 28.6 ± 0.9, range 27-30). All participants were voluntarily participating in the experiment, and all signed a written informed consent form before their inclusion. Younger people received course credit for their participation.

2.2. Apparatus

The participants sat on a chair in front of a table in a dimly lit room. A laptop (Dell, 15', 1768*724) and a felt marker were on the table. A keyboard was accessible to the participants so that they could easily provide their responses by pressing the buttons associated with the "yes" or "no" answers.

2.3. Primes and Stimuli

For the language-action task, the primes included 15 action verbs (see Appendix 1) selected from the lexique3 database (http://www.lexique.org, New et al., 2001). All verbs were presented in French in the infinitive form. The stimuli included 30 pictures, with 15 representing concrete objects and 15 representing human actions. All images were selected from the French database Clic images 2.0, which provides royalty-free illustrations (see Clic-Image2-0 -Réseau Canopé http://www.cndp.fr/crdp-dijon/clic-images/). All images were presented on a computer with a dimension of 960*720 pixels. Vertical and horizontal resolutions were 96 dpi. All images used are presented in Appendix 2.

[1] No a priori calculation was made because no previous study has used the same paradigm. However, previous studies using action verbs as prime and visual judgements as target have shown that 18 participants are sufficient to have a significant difference (at p < .05) with a power of 0.80 (see Bidet-Ildei, Sparrow & Coello, 2017).

2.4. Procedure

The experiment comprised three phases with a duration of approximately 20 minutes. First, all participants completed the language-action task. This task was performed with the software E-prime 2 (https://pstnet.com/welcome-to-e-prime-2-0/). The task comprised 49 trials (4 training and 45 experimental) during which participants first heard an action verb and then had to judge as quickly as possible if an image contained a person or not. Of the 45 experimental trials, 15 presented a congruent relationship between the prime and the stimulus (e.g., the participant heard the verb "run" and then saw an image representing a running movement), 15 trials presented an incongruent relationship between the prime and the stimulus (e.g., the participant heard the verb "run" and then saw an image representing a drawing movement) and 15 trials presented no relationship (i.e., the participant heard an action verb and then saw an image that did not contain a person). These last kinds of trials were not analyzed; they were only present to develop a task for participants. To answer, the participants had to click on the letter A (with the left hand) or P (with the right hand) on an azerty keyboard.

The response buttons were indicated by different color stickers. The response "yes" was always entered with the preferred hand of the participants. Response accuracy and response time were recorded for each trial. After the participants responded, they had to verbally reported verb presented in prime to ensure that they processed it correctly during the priming. No time limit was given for this task, but the experimenter encouraged the participants to be spontaneous. The procedure is presented in Fig. 1.

Subsequently, a recognition task was performed. The experimenter presented each action image used in the action-language task (15 images) and asked the participants to name the represented action, without time constraints. For each image, the experimenter checked the response to ensure that participants knew the correct corresponding action verb. Fig. 2.

2.5. Analysis of the results

For the language-action task, accuracy of responses, accuracy of verbal report and response times (for correct answers and correct repetitions only) were analyzed. We also calculated the differences between the incongruent conditions and congruent conditions as an index of the link between action and language (Beauprez & Bidet-Ildei, 2017). For the recognition task, we calculated the percentage of correct responses for each participant.

Given that all these variables did not respect the principle of normality (all $p < 0.05$ with Shapiro-Wilk normality test for at least one group), we used non parametric independent and dependent comparisons to assess respectively the differences between young and old participants (with the Mann-Whitney U test) and the differences between congruent and incongruent conditions (with the sign test). For all comparisons, we considered as significant the difference for $p < .05$. The data that support the findings of this study are openly available in figshare at http://doi.org/10.6084/m9.figshare.11426550.

3. Results

3.1. Language-action task

Regarding the percentage of correct responses, the analysis showed no difference between younger and older people across congruent ($U = 221.5$; $p = .52$) and incongruent ($U = 246.5$; $p = .94$) conditions and no difference between the incongruent and congruent conditions in young ($Z = 0$; $p = 1$) and old participants ($Z = 0.89$; $p = .37$). For both congruent and incongruent conditions, both age groups had a percentage of correct responses between 87.5 and 100% (mean congruent = 99.2%, SD = 2.5%; mean incongruent = 98.7%, SD =

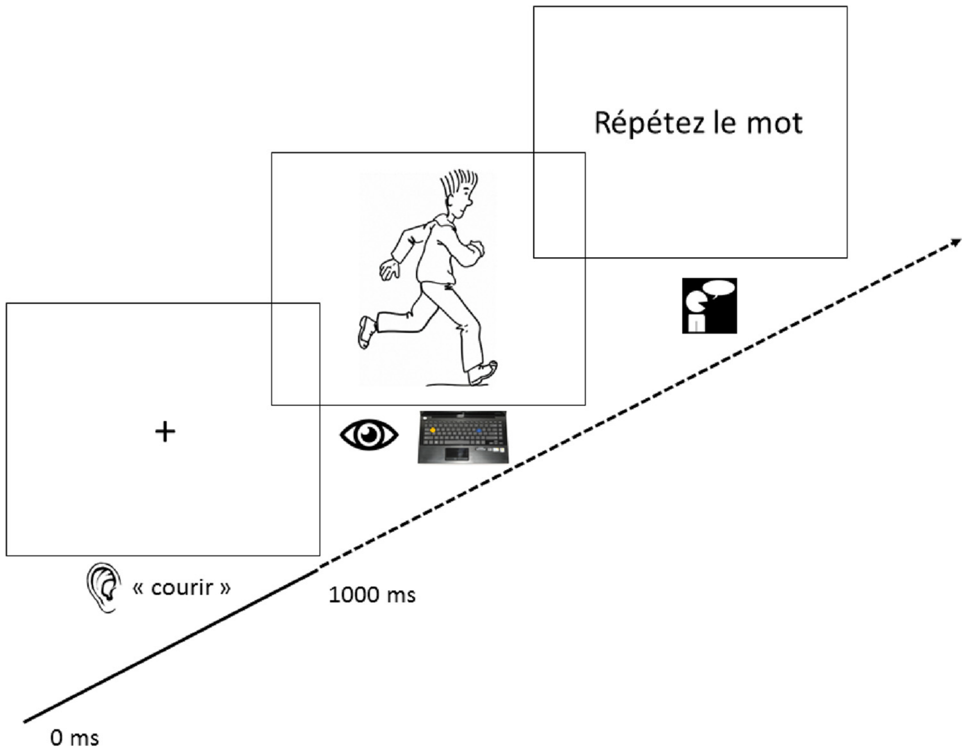

Fig. 1. Procedure used in the experiment. For each trial, the participant listened to an action verb and judged as quickly and accurately as possible if a static image contained or not a person. After the response was made, the participant verbally reported the word presented in prime without a time constraint.

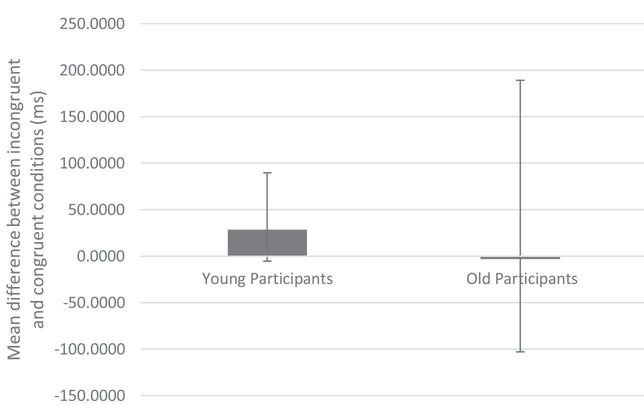

Fig. 2. Mean differences between incongruent and congruent conditions for younger and older participants. Error bars represent the 95% confidence interval.

2.5%).

Regarding the percentage of correct repetitions, the analysis showed no difference between younger and older people across congruent (U = 225; p = .56) and incongruent conditions (U = 212.5; p = .40) and no difference between the incongruent and congruent conditions in both age groups (No enough variability to make the test)). For both congruent and incongruent conditions, both age groups had a percentage of correct repetition between 93.3 and 100% (mean congruent = 99.7%, SD = 1.3%; mean incongruent = 99.5%, SD = 1.7%).

Regarding the response times, the analysis showed an effect of age for congruent (U = 24; $p < .05$) and incongruent (U = 32; $p > .05$) conditions. For both the congruent and incongruent conditions, younger people (mean congruent = 626.2 ms, SD = 170.7 ms; mean incongruent = 654.9 ms, SD = 175.7 ms) had faster response times than older people (mean congruent = 1377 ms, SD = 474.2 ms; mean incongruent = 1374.6 ms, SD = 491.3 ms). Moreover, the younger participants present a difference between congruent and incongruent conditions (mean difference = 28.6 ms, SD = 43.9 ms; Z = 2; $p <$ .04) but not the older participants (mean difference = -2.9 ms, SD = 131.4 ms; Z = -0.2; p = .82).

Furthermore, when we looked the individual distribution of participants concerning the presence of a link between action and language (i.e., when there was a difference between incongruent and congruent trials), it clearly appeared that the interindividual variability in performance increased with age (see Fig. 3). Moreover, the number of participants who presented a positive difference between incongruent and congruent trials (i.e., a link between language and action) had a tendency to decrease significantly with age, with 72% of younger participants and 50% of older participants showing this link (chi^2 (1) = 2.3; p = .13).

3.2. Recognition task

The analysis showed a difference in recognition (U = 127; $p <$

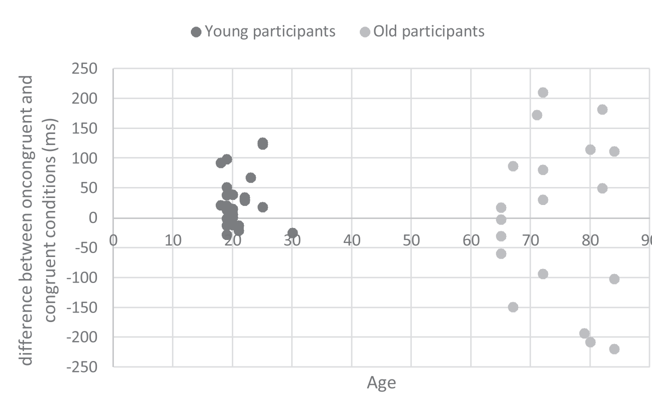

Fig. 3. Individual representations of the difference between incongruent and congruent conditions. Positive values indicate the presence of a link between action and language.

.05) with lower accuracy in the younger (mean = 92.4%; SD = 8.3%) than the older (mean = 99.7%; SD= 1.5%, $p < .001$) participants.

4. Discussion

The present study aimed to assess the link between action and language with aging. For this, we compared the performances of younger and older participants in a priming task consisting of judging whether an image contained a human after listening to an action verb. The results showed that younger people performed better in the congruent than incongruent conditions, whereas this effect was not present in the older participants. Importantly, this effect was not linked with a misunderstanding of the task or lower knowledge of action verbs, as indicated by the similar accuracy scores between the younger and older participants and by a stronger recognition of action by older than younger participants. The findings obtained in younger people largely agreed with previous literature and confirm with static images that the judgments of action verbs affect the subsequent perceptive competencies to judge human movements (Bidet-Ildei et al., 2011; 2017a; 2017b).

Considering the embodied view of cognition (Barsalou, 1999, 2008) and the number of studies demonstrating the functional equivalence between action observation and action language processing (e.g., Aziz-Zadeh et al., 2006; Moreno et al., 2013), we can speculate that this effect was related to the activation of action representations during action verb processing (Bidet-Ildei et al., 2011). Therefore, the absence of an effect in older participants could be due to difficulty in activating and/or using motor representations during action verb processing. This view agrees with recent findings that suggested a default in embodiment in older people (Costello & Bloesch, 2017). Moreover, it is also in accordance with studies that have demonstrated that aging impaired motor simulation and motor imagery (Gabbard et al., 2011; Mulder et al., 2007; Personnier, Ballay, et al., 2010; Personnier, Kubicki, et al., 2010; Personnier et al., 2008; Saimpont et al., 2010, 2009; Skoura et al., 2005, 2008).

Relating these difficulties to motor imagery, we can suppose that older people have more difficulty than younger people in systematically activating the motor representations associated with an action verb. This effect could be related to a modification of the link between action and language throughout life. Indeed, following the “associationist theory”, which proposes that the link between action and language is gradually built from the repeated associations between the activation of the motor system and the activation of the language system (Pulvermüller, 1996, 1999, 2005), we can speculate that the link between action and language would follow an inverted U-shaped pattern during development. Actually, we can suppose that associations between action and language could increase in childhood related to the increase in common activation of language and motor systems when the meaning of the words are learned but that these associations could decrease in adults related to more abstract competencies and fewer associations between action language and motor practice. In this context, it is possible that action verbs are less embodied in older than younger people. Future studies should precisely assess this possibility.

Alternatively, it is possible that the absence of the link between action and language could be related to the discrepancy between the observed actions and the simulated actions by the older adults. Indeed, the majority of the characters present in the images were young, and we know that the activation of sensory-motor representations in language processing is related to the motor experience of the participants (Lyons et al., 2010; Tomasino et al., 2012). Thus, if older adults activate a sensorimotor representation different from the perceived image, we can assume that all situations become incongruent, and it is therefore normal to have no difference. However, this hypothesis remains less probable because other studies have shown that the link between action and language could appear independent of the possibility of simulating the perceived action at the motor level. Even with actions that cannot be practiced (nonhuman actions, modified human actions), the link between action observation and action language processing remains observable (Beauprez & Bidet-Ildei, 2018; Beauprez et al., 2019). Moreover, we have shown with the same material and the same task that the link between action and language appears with younger children (from 8 years) although no child is represented in the images (Bidet-Ildei, Beauprez & Toussaint, in preparation).

Another possibility to explain the difference between younger and older participants could result from the sex ratio between the groups. In fact, there was only 36% of women in the younger group, whereas 85% of the older participants were women. We can hypothesize that women are less performant than men in action-language tasks. Future studies should clarify this point. However, this hypothesis is improbable if we consider the literature demonstrating that women are better than men concerning action observation tasks (e.g., Bidet-Ildei & Bouquet, 2014; Pavlova et al., 2015) and that women and men are also efficient in language tasks (e.g., Parsons et al., 2005).

Importantly, the disappearance of the action-language link in aging could also be related to the decrease in some cognitive functions such as speed processing (see Salthouse, 1985) or executive functions (see West, 1996). Some authors have proposed that cognitive function declines are mediated by age-related decrements in the speed of processing (Salthouse, 1991) or inhibition (Hasher & Zacks, 1988). It would therefore be interesting to clarify these findings by testing the possible mediating role of these variables.

Finally, the finding that the interindividual variability increased with age was in agreement with the concept of cognitive reserve (see Stern, 2009). According to this theory, some related life factors (e.g., educational level, physical activity level, etc.) may moderate the performance level of individuals, causing different trajectories of cognitive aging and consequently amplifying the individual heterogeneity in aging. Hence, it remains possible that the older participants exhibiting an action-language link have a best cognitive reserve compared to the other older participants. Future studies should pay attention to this question, for example, by analyzing older adults in different groups according to their physical activity level or their educational level.

5. Conclusion

Using a priming task, the present work demonstrates that the link between action-verb processing and human action observation decreases with age. Future studies will have to precisely determine the mechanisms underlying this effect and the consequences of this decline for the use of action-language links in reeducation.

Conflict of interest

There is no conflict of interest.

Acknowledgements

Elise Denichou, Renaud Jusiak, Clara Legrand and Vanina Reusa Verdoni, students at the University of Poitiers, conducted part of this work.

Appendix 1 The verbs used in the experiment with the frequency, the number of letters and the number of syllables from http://www.lexique.org

Verb	Frequency (per million occurrences in the corpus of subtitles)	Number of letters	Number of syllables
Boire (Drink)	142.15	5	1
Chanter (Sing)	48.12	7	2
Courir (Run)	47.19	6	2
Cueillir (Pick)	6.26	8	2
Danser (Dance)	70.06	6	2
Dessiner (Draw)	9.1	8	3
Frapper (Knock)	37.08	7	2
Lire (Read)	89.58	4	1
Manger (Eat)	207.63	6	2
Marcher (Walk)	85.34	7	2
Monter (Climb)	85.7	6	2
Nager (Swim)	18.71	5	2
Patiner (Skate)	1.26	7	3
Saluer (Salute)	11.85	6	2
Sauter (Jump)	57.89	6	2

Appendix 2 Action and concrete images used in the experiment

All images were selected from the French database Clic images 2.0 (see Clic-Image2-0 -Réseau Canopé http://www.cndp.fr/crdp-dijon/clic-images/).

Appendix 3 Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.archger.2020.104099.

References

Aziz-Zadeh, L., Wilson, S. M., Rizzolatti, G., & Iacoboni, M. (2006). Congruent embodied representations for visually presented actions and linguisticphrases describing actions. *Current Biology, 16*(18), 1818–1823. https://doi.org/10.1016/j.cub.2006.07.060.

Barsalou, L. W. (1999). Perceptual symbol systems. *Behavioral Brain Sciences, 22*(4), 577–609 discussion 610-60. (11301525).

Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology, 59*, 617–645. https://doi.org/10.1146/annurev.psych.59.103006.093639.

Beauprez, S. A., & Bidet-Ildei, C. (2017). Perceiving a biological human movement facilitates action verb processing. *Current Psychology,* 1–5. https://doi.org/10.1007/s12144-017-9694-5.

Beauprez, S. A., & Bidet-Ildei, C. (2018). The kinematics, not the orientation, of an action influences language processing. *Journal of Experimental Psychology. Human Perception and Performance*. https://doi.org/10.1037/xhp0000568.

Beauprez, S. A., Bidet-Ildei, C., & Hiraki, K. (2019). Does watching Han Solo or C-3PO similarly influence our language processing? *Psychological Research*. https://doi.org/10.1007/s00426-019-01169-3.

Bidet-Ildei, C., Beauprez, S. A., & Badets, A. (2020). A review of literature on the link between action observation and action language: advancing a shared semantic theory. *New Ideas in Psychology, 58*, 100777. https://doi.org/10.1016/j.newideapsych.2019.100777.

Bidet-Ildei, C., & Bouquet, C. A. (2014). Motor knowledge modulates attentional processing during action judgment. *Athens Journal of Social Sciences, 2,* 249–262.

Bidet-Ildei, C., Gimenes, M., Toussaint, L., Almecija, Y., & Badets, A. (2017a). Sentence plausibility influences the link between action words and the perception of biological human movements. *Psychological Research, 81*(4), 806–813. https://doi.org/10.1007/s00426-016-0776-z.

Bidet-Ildei, C., Gimenes, M., Toussaint, L., Beauprez, S. A., & Badets, A. (2017b). Painful semantic context modulates the relationship between action words and biological movement perception. *Journal of Cognitive Psychology, 29*(7), 821–831. https://doi.org/10.1080/20445911.2017.1322093.

Bidet-Ildei, C., Sparrow, L., & Coello, Y. (2011). Reading action word affects the visual perception of biological motion. *Acta Psychologica (Amst), 137*(3), 330–334. https://doi.org/10.1016/j.actpsy.2011.04.001.

Bidet-Ildei, C., & Toussaint, L. (2015). Are judgments for action verbs and point-light human actions equivalent? *Cognitive Processing, 16*(1), 57–67. https://doi.org/10.1007/s10339-014-0634-0.

Birren, J. E., Schaie, K. W., Abeles, R. P., Gatz, M., & Salthouse, T. A. (2006). *Handbook of the Psychology of Aging.* Gulf Professional Publishing.

Boulenger, V., Roy, A. C., Paulignan, Y., Deprez, V., Jeannerod, M., & Nazir, T. A. (2006). Cross-talk between language processes and overt motor behavior in the first 200 msec of processing. *Journal of Cognitive Neuroscience, 18*(10), 1607–1615 (17014366).

Cooper, L. A., & Shepard, R. N. (1975). Mental transformation in the identification of left and right hands. *Journal of Experimental Psychology: Human Perception and Performance, 1*(1), 48–56. https://doi.org/10.1037/0096-1523.1.1.48.

Costello, M. C., & Bloesch, E. K. (2017). Are older adults less embodied? A review of age effects through the lens of embodied cognition. *Frontiers in Psychology, 8*, 267. https://doi.org/10.3389/fpsyg.2017.00267.

Farina, E., Baglio, F., Pomati, S., D'Amico, A., Campini, I. C., Di Tella, S., & Pozzo, T. (2017). The mirror neurons network in aging, mild cognitive impairment, and Alzheimer disease: A functional MRI Study. *Frontiers in Aging Neuroscience, 9*. https://doi.org/10.3389/fnagi.2017.00371.

Fischer, M. H., & Zwaan, R. A. (2008). Embodied language: a review of the role of the motor system in language comprehension. *Quarterly Journal of Experimental Psychology (Colchester), 61*(6), 825–850 (18470815).

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research, 12*(3), 189–198.

Gabbard, C., Caçola, P., & Cordova, A. (2011). Is there an advanced aging effect on the ability to mentally represent action? *Archives of Gerontology and Geriatrics, 53*(2), 206–209. https://doi.org/10.1016/j.archger.2010.10.006.

Hasher, L., & Zacks, R. T. (1988). *Working memory, comprehension, and aging: A review and a new view. In Psychology of learning and motivation, 22*, Academic Press193–225.

Iacoboni, M., & Dapretto, M. (2006). The mirror neuron system and the consequences of its dysfunction. *Nature Reviews Neuroscience, 7*(12), 942–951 (17115076).

Jirak, D., Menz, M. M., Buccino, G., Borghi, A. M., & Binkofski, F. (2010). Grasping language–a short story on embodiment. *Consciousness and Cognition, 19*(3), 711–720. https://doi.org/10.1016/j.concog.2010.06.020.

Lyons, I. M., Mattarella-Micke, A., Cieslak, M., Nusbaum, H. C., Small, S. L., & Beilock, S. L. (2010). The role of personal experience in the neural processing of action-related language. *Brain and Language, 112*(3), 214–222. https://doi.org/10.1016/j.bandl.2009.05.006.

Moreno, I., de Vega, M., & Leon, I. (2013). Understanding action language modulates oscillatory mu and beta rhythms in the same way as observing actions. *Brain Cognition, 82*(3), 236–242. https://doi.org/10.1016/j.bandc.2013.04.010.

Mulder, Th, Hochstenbach, J. B. H., van Heuvelen, M. J. G., & den Otter, A. R. (2007). Motor imagery: The relation between age and imagery capacity. *Human Movement Science, 26*(2), 203–211. https://doi.org/10.1016/j.humov.2007.01.001.

New, B., Pallier, C., Ferrand, L., & Matos, R. (2001). Une base de données lexicales du français contemporain sur internet: LEXIQUE. *L'Année Psychologique, 101*, 447–462. http://www.lexique.org.

Parsons, T. D., Rizzo, A. R., Zaag, C. van der, McGee, J. S., & Buckwalter, J. G. (2005). Gender differences and cognition among older adults. *Aging, Neuropsychology, and Cognition, 12*(1), 78–88. https://doi.org/10.1080/13825580590925125.

Pavlova, M., Sokolov, A. N., & Bidet-Ildei, C. (2015). Sex differences in the neuromagnetic cortical response to biological motion. *Cerebral Cortex (New York, N.Y.: 1991), 25*(10), 3468–3474. https://doi.org/10.1093/cercor/bhu175.

Personnier, P., Ballay, Y., & Papaxanthis, C. (2010). Mentally represented motor actions in normal aging: III. Electromyographic features of imagined arm movements. *Behavioural Brain Research, 206*(2), 184–191. https://doi.org/10.1016/j.bbr.2009.09.011.

Personnier, P., Kubicki, A., Laroche, D., & Papaxanthis, C. (2010). Temporal features of imagined locomotion in normal aging. *Neuroscience Letters, 476*(3), 146–149. https://doi.org/10.1016/j.neulet.2010.04.017.

Personnier, P., Paizis, C., Ballay, Y., & Papaxanthis, C. (2008). Mentally represented motor actions in normal aging: II. The influence of the gravito-inertial context on the duration of overt and covert arm movements. *Behavioural Brain Research, 186*(2), 273–283. https://doi.org/10.1016/j.bbr.2007.08.018.

Pulvermüller, F. (1996). Hebb's concept of cell assemblies and the psychophysiology of word processing. *Psychophysiology, 33*(4), 317–333.

Pulvermüller, F. (1999). Words in the brain's language. *The Behavioral and Brain Sciences, 22*(2), 253–279 discussion 280-336.

Pulvermüller, F. (2005). Brain mechanisms linking language and action. *Nature Review Neuroscience, 6*(7), 576–582. https://doi.org/10.1038/nrn1706.

Saimpont, A., Malouin, F., Tousignant, B., & Jackson, P. L. (2013). Motor imagery and aging. *Journal of Motor Behavior, 45*(1), 21–28. https://doi.org/10.1080/00222895.2012.740098.

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 of Gerontology and Geriatrics, 51*(3), e41–45. https://doi.org/10.1016/j.archger.2009.11.010.

Saimpont, A., Pozzo, T., & Papaxanthis, C. (2009). Aging Affects the Mental Rotation of Left and Right Hands. *PLOS ONE, 4*(8), e6714. https://doi.org/10.1371/journal.pone.0006714.

Salthouse, T. A. (1991). Mediation of adult age differences in cognition by reductions in working memory and speed of processing. *Psychological Science, 2*, 179–183.

Salthouse, T. A. (1985). *Speed of behavior and its implications for cognition. In J. E. Birren & K. W. Schaie (Eds.), Handbook of the psychology of aging.* New York: Van Nostrand Reinhold400–426.

Shafto, M. A., & Tyler, L. K. (2014). Language in the aging brain: The network dynamics of cognitive decline and preservation. *Science, 346*(6209), 583–587. https://doi.org/10.1126/science.1254404.

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*(2), 229–239. https://doi.org/10.1016/j.bbr.2005.07.023.

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; a Journal Devoted to the Study of the Nervous System and Behavior, 44*(9), 1271–1278. https://doi.org/10.1016/j.cortex.2007.07.008.

Stern, Y. (2009). Cognitive reserve. *Neuropsychologia, 47*(10), 2015–2028. https://doi.org/10.1016/j.neuropsychologia.2009.03.004.

Tettamanti, M., Buccino, G., Saccuman, M. C., Gallese, V., Danna, M., Scifo, P., & Perani, D. (2005). Listening to action-related sentences activates fronto-parietal motor circuits. *Journal of Cognitive Neuroscience, 17*(2), 273–281. https://doi.org/10.1162/0898929053124965.

Tomasino, B., Guatto, E., Rumiati, R. I., & Fabbro, F. (2012). The role of volleyball expertise in motor simulation. *Acta Psychologica, 139*(1), 1–6. https://doi.org/10.1016/j.actpsy.2011.11.006.

Tyler, L. K., Cobb, H., & Graham, N. (1992). *Spoken language comprehension: An experimental approach to disordered and normal processing.* Cambridge, MA, US: The MIT Press.

West, R. L. (1996). An application of prefrontal cortex function theory to cognitive aging. *Psychological bulletin, 120*(2), 272.

Willems, R. M., & Hagoort, P. (2007). Neural evidence for the interplay between language, gesture, and action: a review. *Brain Langage, 101*(3), 278–289 (17416411).

Willems, R. M., Toni, I., Hagoort, P., & Casasanto, D. (2010). Neural dissociations between action verb understanding and motor imagery. *Journal of Cognitive Neuroscience, 22*(10), 2387–2400. https://doi.org/10.1162/jocn.2009.21386.