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The possibility of linking spontaneous and induced neurocognitive plasticity: Can cognitive training influence compensatory brain activity in older adults? Theoretical and empirical premises

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SUMMARY

One of the most important determinants of successful aging is cognitive ability. Although cognitive decline is a well-documented phenomenon characteristic of aging, it is acknowledged that aging can also be related to cognitive neuroplasticity that allows one to compensate the decline and adapt to it. Cognitive neuroplasticity may be spontaneous or induced by external influences. An example of the former is compensatory brain activity in older adults, and the latter – improvement in cognitive functioning under the influence of cognitive training. Both the compensatory brain activity of older adults and the effectiveness of cognitive training in this age group have already been extensively studied. However, it has not yet been examined whether they can be linked. The article indicates theoretical and empirical premises for the possibility of influencing compensatory brain activity in older adults by cognitive training. In the most comprehensive way the phenomenon of compensatory brain activity in older adults is addressed by the STAC model – the Scaffolding Theory of Aging and Cognition, which also provides the theoretical grounds for the possible impact of cognitive training on compensatory brain activity. There are also empirical arguments in favour of such an impact, but they are quite limited in nature. The reason for this is the lack of research directly addressing the problem of the consistency of brain activity changes resulting from cognitive training with the assumptions of compensatory brain activity models, such as STAC. The theoretical grounds for the linkage of compensatory brain activity in older adults with the influence of cognitive training are clear. However, the analysis of the studies discussed in the article suggests that failing to embed the study design within the theoretical framework of compensatory brain activity in older adults may lead to the exclusion of factors important in drawing conclusions about this phenomenon. The following elements of the study design were identified as necessary to include: participation of young adults in the study as a reference group, usage of tasks in different difficulty levels during the measurement of brain activity and consideration of the relation between brain activity and cognitive performance, and comparison of brain activity in relation to cognitive performance before and after training in both, older and young adults.

Key words: neurocognitive aging, compensatory brain activity, cognitive training, neuroplasticity

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INTRODUCTION

The issue of aging and old age is currently of particular importance due to the phenomenon of aging populations. The UN Department of Economic and Social Affairs predicts that the world population of persons over 60 will increase to around 2 billion by 2050 (World Population Aging 2015, ST / ESA / SER.A / 390). This trend also applies to Polish society (Leszko, Zajac-Lamparska, & Trempala, 2015). The main reason for the increase in the average length of human life is the extension of life in old age (Szukalski, 2008). The E60 index, which is an indicator of the average life expectancy of sixty-year-old persons, has been growing steadily in Poland since 1992 (GUS, 2018). As a result, old age is not only experienced by a growing percentage of persons, but also, on an individual basis, for longer and longer. It draws attention to the perspective of the personal, subjective experience of late adulthood as a developmental stage and the importance of its psychological aspects.

One of the most important determinants of successful aging and quality of life in late adulthood is considered to be cognitive ability (Castro-Lionard et al., 2011; Hartley et al., 2018; Kim & Kim, 2013; Kryla-Lighthall & Mather, 2009; Martin et al., 2015; Saraçlı et al., 2015). The level of cognitive functioning is also important for the independence of older adults (Cantarella, Borella, Carretti, Kliegel, & de Beni, 2016; Rebok et al., 2014; Tomaszewski Farias et al., 2017), their self-esteem (Chambon & Herrera, 2014), communication skills (Lindquist, Gendron, Barrett, & Dickerson, 2014; Murman, 2015; Virtanen et al., 2017) and family relationships (Harwood, Leibowitz, Lin, Morrow, & Savundranayagam, 2012; Williams & Kemper, 2010). At the same time, cognitive decline is a well-documented phenomenon characteristic of aging (e.g. Buitenweg, Murre, & Ridderinkhof, 2012; Harada, Love, & Triebel, 2013; Salthouse, 2004). It is related to the changes that are observed with age in brain volume and activity (e.g. Raz et al., 2005; Dennis & Cabeza, 2008; Grady, 2008; Hedden, 2013). Nevertheless, it is acknowledged that aging can also be related to positive processes that allow one to compensate the decline and adapt to it, both at the cognitive and neural levels (Barulli & Stern, 2013; Goh & Park, 2009; Greenwood, 2007).

These phenomena are known as cognitive plasticity or cognitive neuroplasticity. Cognitive neuroplasticity is understood as neural changes driven by a prolonged mismatch between the current organismic supplies and environmental demands, leading to an improvement in cognitive functioning (Lövdén, Bäckman, Lindenberger, Schaefer, & Schmiedek, 2010). These changes may be spontaneous or induced by external influences. In the first case, we are dealing with the compensation of losses caused by reduced possibilities thanks to self-activating mechanisms. An example of such mechanisms is the compensatory brain activity of older adults (Cabeza & Dennis, 2012; Zając-Lamparska, 2018). In the second case, there is an increase in the level of functioning in response to environmental influences, examples of which are cognitive interventions, including cognitive training (Greenwood, 2007; Leung et al., 2015).

Both the compensatory brain activity of older adults and the effectiveness of cognitive training in this age group have already been extensively studied. However, the two phenomena have not yet been linked together in common research projects. In this context, the aim of the article is to present the theoretical and empirical premises for the possibility of influence on compensatory brain activity in older adults through cognitive process-based training.

COMPENSATORY BRAIN ACTIVITY AS A SPONTANEOUS COGNITIVE NEUROPLASTICITY

In general terms, compensatory brain activity in older adults can be described as the recruitment of additional brain areas and/or increased brain activity in certain areas, observed in older adults, and associated with a higher level of cognitive functioning. Increased brain activity in older adults in comparison to younger participants has been observed in numerous studies. Many of these studies suggest that this phenomenon is related to a better performance in cognitive tasks amongst older adults. These observations have led researchers to a conclusion as to the compensatory nature of this over-activation pattern, which emerges in response to the negative consequences of age-related changes in the brain (Goh & Park, 2009; Grady, 2008; Park & Reuter-Lorenz, 2009). Compensatory brain activity in older adults has been confirmed by numerous studies utilizing fMRI and PET scans (e.g. Cabeza & Dennis, 2012; Mattay et al., 2006; Dennis & Cabeza, 2008; Reuter-Lorenz & Cappell, 2008; Schneider-Garces et al., 2010; Collins & Mohr, 2012; Kirova, Bays, & Lagalwar, 2015).

The most frequently observed patterns of compensatory brain activity in older adults concern the following: (a) over-activation of the prefrontal cortex in general or those regions of the prefrontal cortex that show low activity in young people; (b) activity of regions of the prefrontal cortex analogous to those active in young adults but located in the counter-hemisphere (Dennis & Cabeza, 2008; Reuter-Lorenz & Park, 2014).

There are two approaches existing in the subject literature that describe the pattern of brain activity that carries compensatory potential for the cognitive functioning of the elderly:

Over-activation of prefrontal regions with a simultaneous activation decrease in the occipital region are known as the PASA pattern – *Posterior-Anterior Shift in Aging.* PASA was first reported in a visual-processing study (Grady et al., 1994). It was also observed in the case of tasks engaging attention and working memory (Cabeza et al., 2004; Dennis & Cabeza, 2008). Its mechanism is supposed to rely on the compensation of automatic processes (such as sensory processes or encoding) through more controlled processing based on internal command and top-down processing (Dennis & Cabeza, 2008). Similarly, a crucial role for the prefrontal region in the adaptation to the age-related decline in cognitive efficiency is postulated by the CRUNCH hypothesis – *Compensation-Related Utilization of Neural Circuits Hypothesis* (Reuter-Lorenz & Cappell, 2008). Its significance results from the relationship of the prefrontal cortex with executive functions which in general can be engaged adaptively, also as a mechanism engaged in adaptation to aging.

Hemispheric Asymmetry Reduction in Older Adults (HAROLD) which stands for a reduction in hemispheric asymmetry, i.e. an additional engagement of brain regions contralateral to those normally recruited during a cognitive task performance in younger individuals (Cabeza, 2002). The HAROLD pattern was observed in studies on several cognitive functions such as: attention, control and inhibitory processes, working, semantic and episodic memory, and language functions. It concerned primarily the prefrontal cortex, although in a few cases it was also observed in parietal and temporal cortices (Bellis, Nicol, & Kraus, 2000; Nielson et al., 2002; Dennis & Cabeza, 2008; Collins & Mohr, 2012; Huang, Polk, Goh, & Park, 2012). HAROLD is supposed to reflect the tendency to rely on alternative processing resources in response to the decline of the resources engaged normally. However, additionally recruited brain areas are related either to similar cognitive operations or are responsible for the same operations but on different kinds of stimuli (e.g. visual vs. verbal) (Cabeza, 2002). It is not clear why some older adults exhibit compensatory brain activity and others do not, and what it depends on; whether or not such activity appears during a particular cognitive activity.

EFFECTS OF COGNITIVE TRAINING AS AN INDUCED COGNITIVE NEUROPLASTICITY

An important area of research on induced cognitive neuroplasticity in older adults are the effects of cognitive interventions, including cognitive training, cognitive stimulation, and cognitive rehabilitation (Alves et al., 2013; Bamidis et al., 2014; Simon et al., 2020). Research on the methods improving cognitive performance in older adults has been conducted for many years now and has provided evidence for the effectiveness of various cognitive interventions (Stine-Morrow & Basak, 2011). In the psychology of human development, Paul Baltes was one of the precursors of the use of cognitive training in older adults. He used cognitive training within studies on the plasticity and developmental reserve capacity with a research strategy called “testing-the-limits” (Baltes, 1987). Numerous studies by Baltes and his colleagues have indicated that older adults have the reserve capacity to improve their cognitive performance (Baltes, Kliegl, & Dittmann-Kohli, 1988; Baltes & Lindenberger, 1988; Baltes, Sowarka, & Kliegl, 1989). Nowadays, the number of studies on the effectiveness of cognitive training is large enough to draw conclusions from systematic reviews and meta-analyses. For example, the meta-analysis of thirty-one randomized controlled trials indicated that cognitive-based training is effective for non-demented older adults (Chiu et al., 2017). Similarly, the review of research on cognitive stimulation and cognitive training programs for healthy older participants pointed out that the results are promising for memory, attention, executive functions, and speed of processing (Tardif & Simard, 2011). Lampit, et al. (2014) included in their meta-analysis the results of fifty-two studies on the effectiveness of computerized cognitive training encompassing 4 885 healthy older adults. The overall effect size for training versus control was small but statistically significant. Small to moderate effect sizes were found for nonverbal memory, verbal memory, working memory, processing speed and visuospatial skills. According to the systematic literature review and meta-analysis equally commercially available computerized cognitive training can improve cognitive abilities in older adults (Tetlow & Edwards, 2017). Another systematic review on the clinical significance of commercially available computerized "brain training" programs was summarized in the authors' conclusion that at least some of such software is effective and can supporting healthy ageing (Shah, Weinborn, Verdile, Sohrabi, & Martins, 2017). Moreover, cognitive training enhance the stability of cognitive functioning across adulthood, as indicated by the review of Eschen (2012). Also the systematic review of seven randomised controlled trials with longitudinal follow-up revealed that cognitive training can prevent the onset of dementia in healthy older adults. According to the conclusions of the authors, cognitive training induced strong and persistent protective effects on longitudinal neuropsychological performance (Valenzuela & Sachdev, 2009).

Over the last several years or so, many studies have focused on the effectiveness of the process-based training. Such a kind of training is based on the assumption that cognitive functions can be improved through the repeated exercising of the underlying core mechanisms. Therefore, the tasks employed in process-based training are designed so that they apply to the core processes engaged in a wide spectrum of cognitive activity (Taatgen, 2013; von Bastian & Oberauer, 2013; Zając-Lamparska & Trempała, 2016). Within this category the n-back training task is especially common (Karbach & Verhaeghen, 2014; von Bastian & Oberauer, 2013). Meta-analyses of the influence of process-based cognitive training, such as working memory, attention or executive functions training, in healthy older adults, have demonstrated the effectiveness of such cognitive interventions. It is consistently confirmed that this type of training improves the trained task performance, with a transfer effect also sometimes being indicated (Au et al., 2015; Karbach & Verhaeghen, 2014; Melby-Lervåg & Hulme, 2016; Motes, 2018; Soveri, Antfolk, Karlsson, Salo, & Laine, 2017; Weicker, Villringer, & Thöne-Otto, 2015). Several meta-analyses of studies involving n-back training in adults at various ages have indicated a small but significantly positive effect of such training on *Gf* (Au et al., 2015; Au, Buschkuehl, Duncan, & Jaeggi, 2016; Soveri, Antfolk, Karlsson, Salo, & Laine, 2017; Schwaighofer, Fischer, & Bühner, 2015; Weicker, Villringer, & Thöne-Otto, 2015). According to the recent systematic review and meta-analysis of twenty-two randomized controlled trials on the long-term efficacy of working memory training in healthy older adults, the training effects are sustained for updating, shifting, inhibition and maintenance (Hou et al., 2020). Some of the studies using process-based training prove their greater effectiveness among older adults than in young participants. Such a result has been obtained in the case of working memory (Li et al., 2008; von Bastian, Langer, Jäncke, & Oberauer, 2013) and executive functions (Bherer et al., 2008; Karbach & Kray, 2009) training. This is particularly important as such effects were not observed in the case of strategy-based training, consistently more effective in young persons (Karbach & Verhaeghen, 2014; Stine-Morrow & Basak, 2011). Finally, as it appears from the review comparing the effectiveness of various forms of training in older adults, all types of cognitive training enhanced the absolute stability of cognitive functioning, but the greatest effects were reported for process-based cognitive training (Eschen, 2012).

In conclusion, the results of the research to date clearly indicate the effectiveness of cognitive training in older adults, especially process-based training. However, the question about the possibility of influencing the compensatory activity of the aging brain by cognitive training remains open.

THEORETICAL PREMISES FOR THE POSSIBILITY OF INFLUENCE COMPENSATORY BRAIN ACTIVITY BY COGNITIVE TRAINING – THE STAC MODEL

In the most comprehensive way the phenomenon of compensatory brain activity in older adults is addressed by the STAC model – the Scaffolding Theory of Aging and Cognition, which places this activity in the context of neurocognitive aging in general, taking into account both degenerative changes and potential compensatory mechanisms. It also considers external influences on cognitive functioning, including cognitive training (Park & Reuter-Lorenz, 2009). A revised version of the model, STAC-R, additionally incorporates life-course factors. Nevertheless, this version does not alter the essence of the original model or its core assumptions (Reuter-Lorenz & Park, 2014). The STAC model explains individual differences in cognitive functioning in old age, building upon the interaction of a wide spectrum of adverse factors related to brain aging (structural – cortical thinning, and functional – e.g. less efficient neural communication) and protective factors, which when combined together constitute compensatory scaffolding. This scaffolding can be triggered and influenced by various types of interventions, including physical exercise, meditation or cognitive training (Reuter-Lorenz & Park, 2014). Compensatory scaffolding stands for the phenomena in the aging brain that naturally arise as a response to the new demands generated by the overall age-related decline. An example of such phenomena is the emergence of brain activity patterns that are normally unobserved in earlier developmental periods. The STAC model refers to two such patterns, which are most commonly observed in research and described in the subject literature: over-activation of the prefrontal cortex, and reduction in hemispheric asymmetry, which were described above in this article as the PASA and HAROLD patterns (Park & Reuter-Lorenz, 2009).

In accordance with the STAC model, cognitive training can influence compensatory scaffolding. The authors of the model predict (theoretically) the following aims of such training employed in cognitive interventions for older adults (Park & Reuter-Lorenz, 2009): in individuals that display a significant deactivation or deterioration of the neural networks engaged in the given task execution, the training should trigger additional activity of a compensatory nature (new scaffolds); whereas in persons for whom cognitive tasks are already performed by them relying on compensatory patterns of brain activity, the training should lead to a decrease in compensatory engagement and an improvement of the primary network efficiency (the kind of restoration of brain activity characteristic of young individuals).

However, assumptions about the aims of the training indicated in the STAC model have not been verified empirically so far and there is no research directly addressing the problem of consistency of brain activity changes resulting from cognitive training with the STAC model assumptions.

EMPIRICAL PREMISES FOR THE POSSIBILITY OF INFLUENCE COMPENSATORY BRAIN ACTIVITY BY COGNITIVE TRAINING AND THEIR LIMITATIONS

In proportion to the number of studies into the behavioural effects of cognitive training, studies investigating brain-level dynamics related to training are still far fewer, especially in older adult populations (Bamidis et al., 2014; Buschkuehl, Hernandez-Garcia, Jaeggi, Bernard, & Jonides, 2014; Heinzel et al., 2016). Moreover, the mixed results of research on the influence of cognitive training on neuronal activity are indicated. The effects of cognitive training in older adults were both the increase and decrease of brain structure and functioning. In addition, depending on the region of interest, both increases and decreases in brain structure and functioning were related to the level of cognitive performance (Brinke, Davis, Barha, & Liu-Ambrose, 2017; Constantinidis & Klingberg, 2016; Motes, 2018). It is also stated that emphasis should be placed on linking the neuroimaging of training related changes to their cognitive assessment (Motes, 2018).

As mentioned above, there are no studies aimed explicitly at verifying the STAC model assumptions. Research findings on the training-induced changes in neural activity have been only interpreted post facto in the context of the STAC model or narrower models or patterns of compensatory brain activity in older adults: CRUNCH, PASA, HAROLD (Dennis & Cabeza, 2008; Reuter-Lorenz & Cappell, 2008). To my best knowledge, only two publications have reported so far studies that were designed directly to verify the assumptions of one of the models of compensatory brain activity in older adults – CRUNCH (Heinzel et al., 2016; Heinzel, Rimpel, Stelzel, & Rapp, 2017). However, this model does not address the impact of cognitive training.

The results of some studies on changes in brain activity in older adults under the influence of cognitive training can be interpreted in light of models of compensatory brain engagement in late adulthood, even when the authors themselves do not write about this. At the same time, such interpretations raise doubts.

For example, the recent empirical literature review on functional neurocorrelates of working memory training, which included studies relying on several different training tasks and age populations, indicated that the most common brain areas in which working memory training induced changes were the prefrontal and parietal areas (Constantinidis & Klingberg, 2016). Observed changes concern the level of activity of these brain regions as well as connections between them. The authors emphasize that in the light of reviewed studies the increase in working memory capacity under the influence of training may be accompanied by both an increase and decrease in neuronal activity (assessed on the basis of the BOLD signal). An increase in activity may reflect an increase in the frequency of cell discharges or an increase in the number of active cells while storing information in working memory – which is interpreted as increased engagement. On the other hand, a decrease in activity was interpreted as an indicator of improvement in neuronal efficiency.

Another review, which focused on the neurocorrelates of cognitive training in older adults only, concluded that the results of the studies clearly support the effect of increased neural efficiency as a result of training. This effect was called economization. Moreover, training induced changes in activity were most frequently observed in the frontal and parietal areas (Degen & Schröder, 2014). However, this review took into account not only cognitive training, but also sensorimotor and cardiovascular training.

The changes indicated in the above discussed reviews which occurred in the prefrontal cortex are consistent with the STAC model and correspond to the CRUNCH hypothesis and the PASA pattern. Nevertheless, such an interpretation is neither sufficient nor reliable, not least because similar training-induced changes in the activity of the same brain regions can also be observed in young persons. The results of several fMRI studies which used the n-back paradigm for training purposes and included only a young adult sample, showed that changes in the brain activity related to this kind of training were largely limited to frontal and parietal areas. They manifested themselves as a decrease in the brain activity during the n-back task execution, when the difficulty level of the task was relatively low, i.e. fell within one's capability after training. This was interpreted as an indicator of increased neural efficiency resulting from the replacing of controlled processes by more automatic processes (Buschkuehl et al., 2014). In light of the STAC model, these results could be interpreted as a decrease of compensatory engagement that has become unnecessary thanks to cognitive training (Park & Reuter-Lorenz, 2009). However, in the case of young study participants the interpretation should be different, although the observed changes are similar to those described in the models of compensatory brain activity in older adults.

Several authors in their interpretations of the obtained results refer explicitly to the phenomenon of compensatory brain activity in older adults. In studies by Erickson and colleagues (Erickson et al., 2007a; 2007b), thanks to the single and dual task paradigm, groups of young and older adults improved their performance in terms of reaction times and accuracy to the same extent. In the older group at the neural level these changes were accompanied by: (a) an increase in the left and a decrease in the right ventrolateral prefrontal cortex (VLPFC), and a stronger hemispheric asymmetry; (b) a reduction in the dorsolateral prefrontal cortex (DLPFC) that led to the disappearance of inter-age-group differences. The authors interpreted these results as contradictory to: the HAROLD pattern and the hypothesis about the compensatory role of the prefrontal cortex engagement in older adults respectively. However, they did not take into consideration the task performance before training. In both groups task performance before training was similar, with slightly higher scores in older adults (Erickson et al., 2007b). Considering age-related decline in cognitive functions (which usually is evident in dual tasks), it can be stated that older adults in this study functioned cognitively even better than young participants (if the results are compared to typical individuals in this age group). Consequently, it is possible that older adults already before training relied on compensatory patterns of neural engagement, which allowed them to perform as well as the younger individuals. The training made it possible to substitute these patterns with a brain activity typical of a younger age and thus led to little difference between the age groups after training.

In other research, there was no significant improvement in cognitive performance among older adults after visual-spatial and verbal working memory training due to the ceiling effect, which means that the task was (too) easy for participants. At the same time, at the neuronal level there was a decrease in the activity of dorsolateral prefrontal cortex (DLPFC), as well as of the superior temporal and occipital cortex. Authors have interpreted the observed activity reduction as a marker of neuronal efficiency increase following cognitive training (Brehmer et al., 2011). Such results could be considered to be consistent with the STAC model, even with no changes in behavioural level. However, without information on the occurrence of increased activity in certain brain regions in older adults before training (when compared to younger ones), this conclusion cannot be seen as reliable. Unfortunately such information is missing, as only older people were involved in this study.

On the other hand, in studies where training required an update of the information in the working memory, older adults (as opposed to young participants) experienced an increase in activity in the frontal and parietal regions and striatum, accompanied by an improved cognitive performance. Authors have interpreted this as a lack of automation in the trained task performance in older adults (Dahlin, Bäckman, Neely, & Nyberg, 2009). In the context of the STAC model, it could be claimed that the obtained results reflect a compensatory involvement of the frontoparietal network, which is associated with increased cognitive control. However, this interpretation would only be correct under the assumption that the task was relatively difficult for older participants, and that initially there was no compensatory brain activity in this age group, which we do not know to be the case.

The most recent study reports (Heinzel et al., 2016; Heinzel et al., 2017) on neurocorrelates of the n-back training effects in older adults are at the same time the only ones in which authors directly located their investigations within the context of the compensatory patterns of brain engagement in late adulthood, even though the aim of the study concerned another research problem – cognitive transfer. The reduction in middle frontal gyrus (MFG)/mid-cingulate activation accompanying the task performance increase, which was unveiled in these investigations, was linked by the authors to a decreased control and attentional effort. The right-sided decrease in MFG/caudal superior frontal sulcus (cSFS) activation, on the other hand, is interpreted by the authors as a possible training-related disappearance of the additional compensatory engagement of the right hemisphere described in the HAROLD model (Heinzel et al., 2016). Moreover, the training-induced reduction in DLPFC activity during the low working memory load as well as the increase during the high working memory load supported the transfer-task (specifically dual-task) performance (Heinzel et al., 2017). This finding corresponds to the STAC model assumptions. The study, however, was conducted without the inclusion of young adults, who constitute a reference group fundamental to an assessment of the specificity of brain activity characteristic to old age and to conclude on the compensatory nature of brain activity in older adults. The lack of a young adults group makes it impossible to assess the presence of the neural compensatory engagement in older adults before training, which, in turn, makes the interpretation of the results less robust and certain.

Recent neurophysiological and neuropsychological findings, with the use of functional neuromarkers (especially guantitative electroencephalography, qEEG and event related potentials, ERPs) suggests that in the process of linking spontaneous and induced neurocognitive plasticity an important role is played by the reward /penalty system (see: Pąchalska 2019). Most cognitive experience releases emotions, because it stimulates the reward / punishment system by creating new connections in the brain. Unpleasant cognitive experiences releases negative emotions (e.g. fear) because they stimulate the lateral prefrontal cortex and strengthen the penalty system by experiences felt in dream and by talking about it after waking up. Negative emotions e.g. fear, sadness, are included in the working memory, and, they are remembered in the long term memory, if they are important for the particular person. At the same time, the reward system is weakened (cf. Fig. 1).

Accordingly, pleasant cognitive experiences release positive emotions (e.g. joy), because they stimulate the reward system by creating connections from the basal part of the frontal cortex to the anterior (emotional) part of the anterior cingulate cortex. At the same time, the penalty system is weakened. The strength and duration of the emotions are associated with the importance of the event for

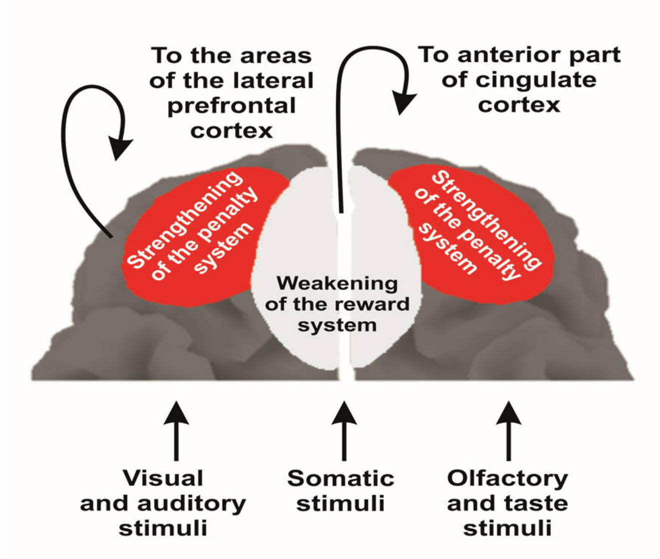

Fig. 1. The reward /penalty system: the medial part involves the processing of the reward, and the lateral part involves the processing of the penalty.
Source: Pąchalska 2019

the trained person. Therefore, cognitive experience might modify the minimal (working) self, and the longitudinal (autobiographical) self, strengthening the significance of a given (negative or positive) event (see Pąchalska 2019). The activation of the reward/penalty systems is not indifferent to the organism, as new connections in the brain can create new neural circuits which might improve spontaneous as well as induced neurocognitive plasticity.

To sum up, two positive phenomena can be observed in the process of neurocognitive aging: compensatory brain activity which is a manifestation of spontaneous cognitive neuroplasticity and an improvement of cognitive functioning under the influence of training, which is an example of induced cognitive neuroplasticity. Despite numerous studies on both of these phenomena, it has not yet been examined whether they can be linked. More specifically, it is unknown whether cognitive training can influence compensatory brain activity in older adults.

The theoretical grounds provided in the STAC model clearly indicate this possibility. There are also empirical premises in favour of such a linkage. However, they do not derive from studies aimed directly at verifying this hypothesis, therefore they are questionable and burdened with many shortcomings. The analysis of the studies discussed in this article suggests that failing to embed the study design within the theoretical framework of compensatory brain activity in older adults may lead to the exclusion of factors important to draw conclusions about this phenomenon. These factors comprise: (a) The participation of young adults in the study as a reference group. Models of compensatory of brain activity in older adults assume that this activity is increased or additional in relation to that observed in young persons, therefore a comparison between participants from different age groups is necessary; (b) The employment of tasks in various difficulty levels during the measurement of brain activity and a consideration of the relation between brain activity and cognitive performance. Compensatory brain activity is a phenomenon that does not have to be observed permanently in an aging brain. It can accompany the increased demands of the task and contribute to its proper performance; (c) Comparison of brain activity in relation to cognitive performance before and after training in both, older and young adults. Only such a comparison will allow one to evaluate if cognitive training leads to new compensatory scaffolds in the case of neural deterioration in older adults and – in contrast – decreases compensatory engagement in the case that it was already present and makes neuronal activity similar to that observed in young persons. Failure to take these factors into account makes it more difficult or even impossible to interpret the results of a study in the light of compensatory brain activity models, as these are the factors that determine whether the training – according to the STAC model – should trigger compensatory activity or lead to its disappearance (Park & Reuter-Lorenz, 2009).

The analyses presented in this article have become the basis for designing one's own research into the possibility of the impact of cognitive training on compensatory brain activity in older adults, covering all the above mentioned factors. This study is currently underway. The research project is entitled "Compensatory brain activity in older adults. The search for the electrophysiological indicators of cognitive processes involved in this activity, and its possible changes induced by working memory training" and is funded by the National Science Centre, Poland (2017/25/B/HS6/00360).

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