Dual-tasking and aging—About multiple perspectives and possible implementations in interventions for the elderly

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Abstract: It is well known that dual-tasking is adversely affected by physiological degenerative processes. Furthermore, the completion of a secondary task while walking is frequently discussed as a key contributor for falls in the elderly. Age-related differences in both activated neural structures and human behavior are indicated in numerous previous studies. Besides a general overview of dual-tasking and aging, this article reviews studies aiming at improving gait or postural control in older adults using dual- or multi-task interventions. Approximately, 130 parameters out of 17 illustrated studies presented significant changes after dual-task-specific interventions regarding gait, postural control/balance, and falls. On the one hand, the article at hand shows highly consistent results in all of the dual-task intervention studies analyzed, indicating significant improvements related to postural control, gait, falls, or the performance of a secondary task. On the other hand, the results represent a heterogeneous structure and a gap between theoretical aspects and practical use. To optimize the use of dual-task, a systematization of underlying tasks is inevitable and should be focused on in further research.

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PUBLIC INTEREST STATEMENT
We are driving a car while calling a friend, standing in the railway while reading the newspaper, or working on the computer while watching TV. The complexity of our daily life is growing permanently, whereas the ability to handle these situations decreases during the process of aging. Focusing on the simultaneously “talking while walking”, previous studies revealed an increased risk of falling in the elderly, respectively. Based on these findings, and in order to improve the abilities of our aging society to handle these situations, diverse interventions have been developed. While the results consistently indicated improvements in gait, falls, and the performance of a secondary task after finishing the programs, the relation between underlying neurophysiological mechanisms and practical use is still less understood. The present review sheds light on both existing interventions and the underlying neurophysiological mechanisms in order to get a better understanding of its relation and to create a basis for future approaches.
1. Introduction

Dual-task situations nowadays are of increasing relevance. The extent of successful execution depends on many factors and is adversely affected by physiological degenerative processes (Korteling, 1993; Verhaeghen, Steitz, Sliwinski, & Cerella, 2003). Next to the effects on dual-task performance, both motor and cognitive tasks are significantly affected as single components, during the process of aging (MacPherson, Phillips, & Della Sala, 2002; Mattay et al., 2002; Seidler et al., 2010). Against this background, studying dual-task effects on the elderly has become an emerging field of research, especially in the context of gait and postural control (Shumwas-Cook & Woollacott, 2000; Woollacott & Shumway-Cook, 2002). Using dual-task paradigms sheds light on both the influence of age-related changes in terms of stability of apparently simple motor tasks (Woollacott & Shumway-Cook, 2002), as well as the performance of the secondary cognitive tasks (Li, Lindenberger, Freund, & Baltes, 2001; Smolders, Doumas, & Krampe, 2010). Hence, the inevitability of completing further tasks while walking (reading signs, talking to another person, etc.) could be seen as a key contributor of falls and gait impairments in the elderly (Korteling, 1993; Lundin-Olsson, Nyberg, & Gustafson, 1997; Verhaeghen et al., 2003). In this context, Shumway-Cook et al. (2007) investigated age-specific performance of complex walking tasks of 1,227 persons (aged 20–95). The authors found a larger decline in gait speed at age 65 and older, as well as greater differences between the performance of simple and complex walking tasks in older participants compared to younger adults. Furthermore, there was an increased number of older adults who walked under simple low-challenge conditions, but were unable to walk under complex conditions. Investigating cognitive and sensorimotor performance, Li et al. (2001) found greater age-related differences of dual-task costs in memory performance than in walking which is in accordance with the results of Smolders et al. (2010). While Li et al. (2001) suggested that older adults prioritized walking over memory, a conclusion can be drawn on the assumptions of Hausdorff, Yogev, Springer, Simon, and Giladi (2005). Here, the authors speculated that during the process of aging, walking (as automated, rhythmic motor task) becomes a more cognitive task.

Considering the daily relevance of handling dual-task situations as well as the stated reduction of performance during the process of aging, it seems to be obvious that an integration of the dual-task paradigm into training and intervention programs might be useful in order to improve the ability of walking and postural control in older people (Bock, 2008). Although, numerous studies and reviews investigated age-related differences in dual-task performance (e.g. Beurskens & Bock, 2012 for review), the present article aims a more global insight (not limited, e.g. on the motor task “gait”) in the effects of combining cognitive and motor tasks in older adults. Here, we focus on the underlying neurophysiological structures, as well as the influence of motor–cognitive task combinations on both the performance of the cognitive and the motor components. Complementing this consideration, we shed light on studies that aimed preventing falls and improved gait and/or postural control in the elderly using interventions based on motor and cognitive task combinations.

2. Dual-tasking and aging

As already stated in the introduction, the process of aging determines the performance of dual-tasking. The following sections emphasis a general insight into the underlying mechanisms as well as age-related changes.

2.1. Underlying structures in dual-tasking

For better understanding the effects of performing an additional task on behavioral parameters, we would give an insight in how the brain processes these additional demands. Therefore, within this chapter, we reviewed literature that investigated neuronal structures, which were activated in performing dual-tasks, but more importantly, age-related differences. Principally, the activation of structures underlying the process of dual-task could be classified in three different patterns: (1) increase
in activity of structures, already activated under single-task conditions or additional structures; (2) no change in activity; and (3) decrease of neural activity compared to single-task condition. Within Figure 1 are studies focusing on the underlying structures assigned to one of the three categories. Studies reporting a decrease of neural activity in the dual-task compared to single-task condition identified both a specific (Goldberg et al., 1998; Just et al., 2001; Just et al., 2008) as well as a general decrease in activity. While we considered 27 studies, 20 studies reported an increase of activity in dual-task situations. To give an idea about the structures showing a dual-task-related increase in activity or be additionally activated, Figure 2 comprises the results of the 20 studies mentioned above. Here, a large variance of the activated structures during the performance of dual-tasks becomes apparent. Therefore, it is necessary to consider the characteristics of combined tasks in relation to the activated structures. This highlights a problem, which occurred repeatedly at different points in this article.

The dual-task paradigm does not consist of two clearly defined tasks.

While most studies concentrate on the combination of two cognitive tasks, some studies investigate additionally the performance of motor tasks. Here, Wu, Liu, Hallett, Zheng, and Chang (2013) used a dual-task setting consisting of a motor (self-paced tapping) and a cognitive (visual letter counting) task in order to determine additionally activated brain structures during dual-tasking. Structures indicated by Wu et al. (2013) differ clearly from both the results illustrated in Figure 2 as well as the discussion about the prefrontal cortex as a general mechanism for solving dual-task problems (e.g. D’Esposito et al., 1995). Also studies investigating exclusively cognitive task combinations showed an activation of structures not exclusively located in the prefrontal cortex (Szameitat, Schubert, Müller, & von Cramon, 2002). Besides task-related influences (which should be reviewed in detail in a future article), the types of response need to be considered: for example motor (trigger/button) (Dux, Ivanoff, Asplund, & Marois, 2006; Herath, Klingberg, Young, Amunts, & Roland, 2001; Jiang, 2004; Schubert & Szameitat, 2003; Stelzel, Schumacher, Schubert, & D’Esposito, 2006;
Figure 2. Brain structures showing increased activation in dual-compared to single-task condition.
Szameitat et al., 2002) or verbal (Dux et al., 2006; Stelzel et al., 2006) response which has been used in the illustrated studies. This short overview and the stated aspects demonstrate the necessity for further investigations. Here, numerous dual-task situations should be analyzed within one experiment in order to get a deeper insight into the underlying pattern of activation.

Focusing on age-related differences, the following section gives an overview about previous neuroimaging findings. Here, Chmielewski, Yildiz, and Beste (2014) measured brain activity in 14 healthy late middle-aged adults (mean age 60.51 ± 3.34) and 14 young participants (mean age 24.37 ± 2.89), by utilizing the psychological refractory period test. While behavioral data showed an increasing reaction time in late middle-aged participants compared to young subjects, the fMRI data revealed more activation in the occipital regions in late middle-aged subjects compared to younger subjects. Furthermore, during more complex conditions, late middle-aged participants showed lower activations in the middle frontal and superior frontal gyrus. Using visual task combinations with a manual response (movement of right index or right second finger) in an fMRI study, Hartley, Jonides, and Sylvester (2011) identified an involvement of a medial prefrontal network and a lateral frontal–parietal network, largely similar in both younger and older adults. In the older group, a polar prefrontal area seemed to be responsible for top-down management of task goals. Another fMRI study (Van Impe, Coxon, Goble, Wenderoth, & Swinnen, 2011) investigated age-related dual-task effects using both auditory and visuomotor tasks. Here, the authors reported an age-associated increase in brain activation only in the single visuomotor task setting (frontoparietal network). In dual-task situations, both groups showed additional activation in the supplementary motor area/pre-supplementary motor area, anterior insula, and inferior precentral gyrus showing no age-related differences. Using functional magnetic resonance imaging and diffusion tensor imaging, Madden et al. (2010) examined aged-related differences in task switching. The authors concluded that the functional connectivity of frontoparietal activation might be seen as a potential source of age-related decline in executive control.

Results in imaging studies allow for drawing conclusions from activated brain structures to both general abilities as well as age-related differences of performing dual-task. However, the opposite is true in behavioral studies. Here, assumptions regarding the performance of dual-tasking resulting from human behavior are considered.

2.2. Influence of dual-tasking on cognitive behavior in aging

In the field of dual-tasking, classical neuropsychological studies mostly focus on the combination of two cognitive tasks. Based on the well-known psychological refractory period (PRP) (Telford, 1931; Welford, 1952), these experiments often combine simple reaction tasks (visual or auditory) with different stimulus onset asynchronies (SOAs). In varying SOAs, it is found that a decrease in SOA leads to an increased reaction time (RT) of task 2 (PRP-effect) (Kahneman, 1973), whereas the effect on the first task is much smaller (Smith, 1969) and sometimes essentially absent (Pashler, 1994; Pashler & Johnston, 1989). In contrast, Hein and Schubert (2004) reported a significant increase in both RT 1 and RT 2 in older participants during short SOA conditions. While this study used SOAs between 50 ms and 800 ms, SOAs in the study of Glass et al. (2000) varied between 50 ms and 1,000 ms. Besides an overall reduction of reaction time, the authors also reported a significant SOA effect for both task 1 and task 2 (size of effect in task 1 was rather small compared to the effect of task 2) in older adults. While Glass et al. (2000) and Hein and Schubert (2004) concentrated on the examination of different SOA conditions, Vaportzis, Georgiou-Karistianis, and Stout (2013) investigated the simultaneous performance of choice reaction time tasks paired with digit tasks. The authors indicated different behavioral strategies (between younger and older adults) depending on complexity and difficulty of tasks. Compared to younger participants, older adults were significantly slower, but had a lower error rate in performing simple reaction time tasks. However, the opposite was true in the complex choice reaction time tasks. Using neuropsychological tests, Holtzer, Stern, and Rakitin (2005) examined age-related differences in performing dual-tasks in 16 older adults (aged 65–85) and 16 younger adults (19–31). On the one side, the authors pointed out the important role attention placed in mediating dual-task performance. On the other side, they suggested that compromised
central executive might be causal for the decline in dual-task performance. While related studies considered the influence of dual-tasking as cross-sectional investigations, Göthe, Oberauer, and Kliegl (2007) investigated age differences in parallel processing of two cognitive operations through practice (longitudinal approach). The results show that after eight training phases, 9 out of 12 young people were able to process the given tasks, but none of the older adults reached the criterion of parallel processing.

In addition to the effect of performing two cognitive tasks simultaneously, the combination of a motor and a cognitive task needs to be considered. Here, Marsh and Geel (2000) found a significant deterioration in the cognitive RT task during the performed dual-task in older adults. The authors combined a primary quiet standing task (under four conditions) with a secondary verbal reaction time task. In addition, Redfern, Müller, Jennings, and Furman (2002) combined simple standing with randomly implied perturbations, while performing visual and acoustic RT tasks. Regarding cognitive behavior, RT in older participants was shown to be more influenced by perturbation compared to younger ones. While these studies concentrated on quiet standing, Sparrow, Bradshaw, Lamoureux, and Tiros (2002) and Srygley, Mirelman, Herman, Giladi, and Hausdorff (2008) combined different cognitive tasks with the performance of walking. Here, Sparrow et al. (2002) compared 6 young (26.3) and 12 healthy older (71.1) adults in terms of reaction time in three different cognitive tasks while walking. Results showed no age-related differences in single cognitive task conditions, whereas during the simultaneous performance of walking, older adults showed significant longer reaction times in the visual and auditory/visual condition, but not in the auditory condition. Single-task conditions in the study of Sparrow et al. (2002) were analyzed in upright standing, whereas Srygley et al. (2008) investigated cognitive single-tasks in a sitting position. Thereby, Srygley et al. (2008) also used three different cognitive tasks: (1) serial three subtractions, (2) serial seven subtractions, and (3) phoneme monitoring. Older adults showed much larger effect of walking on cognitive performance compared to younger subjects. Furthermore, a current study by Jabourian et al. (2014) indicated gait velocity as an indicator of cognitive performance in healthy middle-aged adults. The authors found both a lower cognitive performance and longer walking time in older subjects compared to younger ones. With respect to these results and the stated findings by Li et al. (2001), which discussed the prioritization of walking over memory in older subjects, it might be necessary to additionally consider the influence of dual-tasks on motor behavior.

2.3. Influence of dual-tasking on motor behavior in aging

Maintaining motor function especially during the influence of additional demands is adversely affected during the process of aging. In this context, Hollman, Kovash, Kubik, and Linbo (2007) investigated parameters of gait during walking while simultaneously performing a cognitive task in three groups (sixty older, middle-aged, young adults). The older group walked slower and had an increased variability in stride velocity compared to the middle-aged and young participants. The authors suggested that the impaired walking performance was associated with impaired cognitive performance in dual-task walking. In the same manner, Dubost et al. (2006) found a decrease in gait velocity and an increase in variability in healthy elderly subjects when walking under dual-task conditions in comparison to free walking. These results are supported by further studies (e.g. Lindenberger, Marsiske, & Baltes, 2000; Priest, Salamon, & Hollman, 2008). According to a study by Springer et al. (2006), each combination of a secondary task with a walking task lead to decreased gait variability in each group (healthy young, healthy elderly non-fallers, and healthy elderly fallers). The authors did not find a difference between younger and older non-fallers. However, a significant difference became apparent when the elderly faller group was taken into account. It might be speculated that with a decrease in executive function, resources to manage the simultaneous processing of conflicting tasks decline. This tendency could be found in postural control studies as well (Brown, Shumway-Cook, & Woollacott, 1999; Shumway-Cook, Woollacott, Kerns, & Baldwin, 1997; Teasdale, Bard, LaRue, & Fleury, 1993). For instance, it has been reported that muscle activity while reacting on platform perturbations is significantly affected by a secondary task, and that this effect is more pronounced in the elderly (Rankin, Woollacott, Shumway-Cook, & Brown, 2000). As stated by Shumway-Cook et al. (1997), higher discriminative effects between healthy younger and healthy elderly
subjects come along with increased task complexity which confirms with other investigative studies (Bernard-Demanze, Dumitrescu, Jimeno, Borel, & Lacour, 2009; Shumwas-Cook & Woollacott, 2000). A competing result is presented by Prado, Stoffregen, and Duarte (2007), who in fact reported an impact of a dual-task design on postural control parameters, but there was no difference between young subjects and elderly subjects when performing the dual-task setting. However, in postural control studies, the main challenge for researchers is the great variety of available parameters which partly leads to contradictional interpretations (Fraizer & Mitra, 2008; Lacour, Bernard-Demanze, & Dumitrescu, 2008). In general, it may be conjectured that strategies underlying postural control with a dual-task paradigm are different in younger compared to older subjects and are based on different task prioritizations (Bernard-Demanze et al., 2009). Within this background, the consideration of effects of dual-tasks-based interventions on gait or postural control seemed to be essential for (1) a better understanding of the underlying modes of action, as well as (2) the development of optimal concepts of intervention.

2.4. Dual-task-based interventions in the elderly

As described in previous chapters, the process of aging leads to a change in activation patterns of involved brain structures, as well as a decline in performance of motor and/or cognitive behavior in dual-task situations. This chapter will review studies investigating the effect of dual-task-based interventions on gait or postural control in the elderly. While numerous interventions unconsciously include dual-tasks, we considered only studies which described interventions explicitly as dual-task. Here, studies could be classified due to the characterization of its intervention: (1) stepping exercises (Yamada, Aoyama, Tanaka, Nagai, & Ichihashi, 2011; Yamada, Aoyama, Hikita et al., 2011), (2) exercises with combined walking and cognitive tasks (You et al., 2009), (3) balance training (Granacher et al., 2010; Melzer & Oddsson, 2013; Plummer-D’Amato et al., 2012; Silsopadol, Shummay-Cook et al., 2009, Silsopadol, Lugade et al., 2009), (4) balance exercises based on activities of daily living (Halvarsson et al., 2011, 2013), (5) computerized training (Li et al., 2010), (6) music-based rhythmic training (Trombetti et al., 2011), (7) combined strength, agility, and balance training (Hijamizu, Moriga, Shomoto, & Shimada, 2012; Uemura et al., 2012), and (8) dance videogame training (Pichierri, Coppe, Lorenzetti, Murer, & de Bruin, 2012; Pichierri, Murer, & de Bruin, 2012; Schoene et al., 2013). Table 1 shows a short characterization of the interventions of considered studies. In relation to the identified studies, balance training has been the most common constituent of dual-task interventions in the elderly with respect to improving gait or postural control. Within these five studies, two studies (Granacher et al., 2010; Melzer & Oddsson, 2013) investigated the combination of exclusively motor tasks, whereas three (Plummer-D’Amato et al., 2012; Silsopadol, Lugade et al., 2009, Silsopadol, Shummay-Cook et al., 2009) examined the effect of simultaneously training motor and cognitive tasks. While both Silsopadol, Shummay-Cook et al. (2009) and Plummer-D’Amato et al. (2012) used balance and gait as motor components, Silsopadol and Lugade et al. (2009) integrated only balance exercises into their intervention program. Both studies of (Silsopadol, Lugade et al., 2009, Silsopadol, Shummay-Cook et al., 2009) additionally focused on different attention strategies. Here, group I was instructed to focus on both cognitive and motor tasks during the whole training, whereas group II was instructed to focus one half of the training on motor and one half of it on cognitive task performance. A comparison of the underlying results of the dual-task studies focusing on balance training shows that only these interventions (Silsopadol, Lugade et al., 2009, Silsopadol, Shummay-Cook et al., 2009) recorded significant changes in gait under dual-tasking. While the condition of fixed priority instruction shows only short-term improvements (Silsopadol, Shummay-Cook et al., 2009) or changes similar to single-task training (Silsopadol, Lugade et al., 2009), the condition of variable priority instruction was more effective in improving both motor and cognitive performance under dual-task (Silsopadol, Lugade et al., 2009) and in maintaining the training effect at the 12-week follow-up (Silsopadol, Shummay-Cook et al., 2009).

While balance training has a long tradition as part of prevention and rehabilitation programs (e.g. Chang et al., 2004 for review), current interventions include more and more video or computerized training (e.g. Kueider, Parisi, Gross, & Rebok, 2012 for review). In the context of dual-task interventions (to improve gait and postural control in the elderly), Pichierri, Coppe et al. (2012), Pichierri,
Murer et al. (2012), and Schoene et al. (2013) included dance videogames in their intervention programs, whereas Li et al. (2010) investigated a computerized exercise program. While interventions based on dance videogames obviously include a motor component, the intervention program investigated by Li et al. (2010) was the only 1 out of 17 studies found which combined two cognitive tasks in order to improve motor behavior in the elderly. Here, participants were trained to make two-choice decisions to visually presented stimuli. The results showed a significant improvement during single-support balance and double-support dynamic balance in the training group, whereas the control group reported no appreciable improvements (Li et al., 2010). Considering parameters of gait, significant changes during the intervention were only observed by Pichierri, Coppe et al. (2012), Pichierri, Murer et al. (2012) (within computerized or video-based dual-task training). Both Pichierri,

| Reference                                | Intervention                                                                 |
|------------------------------------------|-----------------------------------------------------------------------------|
| Granacher et al. (2010)                  | 60 min, three times a week balance training consisted of postural stabilization tasks, intensified by including additional motor interference tasks |
| Hiyamizu et al. (2012)                   | 60 min, twice a week strength and balance training, calculation task, visual search task, and verbal fluency task were performed simultaneously during balance training |
| Pichierri, Coppe et al. (2012)           | 60 min, twice a week cognitive motor intervention with progressive resistance training, progressive postural balance training, and progressive dance video gaming |
| Schoene et al. (2013)                   | 15–20 min, 2–3 sessions per week videogame-based stepping exercise with additional cognitive load |
| Trambetti et al. (2011)                  | 60 min, once a week various music-based multi-task exercises; basic exercise consisted of walking in time to the music and responding to change in the music’s rhythmic patterns |
| Yamada, Aoyama, Tanaka et al. (2011)    | 50 min, once a week aerobic, strength, flexibility, and balance exercise, stepping exercise while performing fluency task, enumerating words within a category or letter |
| Halvarsson et al. (2011)                | 45 min, three times a week exercises comprised elements that represent daily activities; dual/multi-task exercises included counting, reading a newspaper, doing up/undoing buttons, and carrying a tray while walking |
| Li et al. (2010)                         | 60 min computerized dual-task cognitive training; adaptive feedback on the computer screen indicating the participant’s current performance |
| Pichierri, Murer et al. (2012)           | 40 + 10–15 min (game dancing), twice a week progressive resistance training, progressive postural balance training, and additional dance video game |
| Silsupadol, Shummay-Cook et al. (2009)  | 45 min, three times a week dual-task balance and gait training with fixed priority instruction |
| Uemura et al. (2012)                    | 30 min, once a week stretching, agility, and strength exercises; executive motor tasks where performed with cognitive tasks: COP shift exercise, start–stop exercise, and switch exercise |
| Yau et al. (2009)                       | 30 min, five times a week cognitive gait intervention |
| Halvarsson et al. (2013)                | 45 min, three times a week exercises comprised elements that represent daily activities; the dual/multi-tasks included counting, reading a newspaper, doing up/undoing buttons, and carrying a tray while walking |
| Melzer and Oddsson (2013)               | 60 min, twice a week balance training consisted of postural stabilization tasks, intensified by including additional motor interference tasks |
| Plummer-D’Armato et al. (2012)          | 45 min, once a week balance, gait, and agility activities; dual-task training includes cognitive tasks with simultaneous balance and gait activities |
| Silsupadol, Lugade et al. (2009)        | 45 min, three times a week dual-task balance training with fixed priority instruction |
| Yamada, Aoyama, Hikita et al. (2011)    | 20 min, twice a week DVD exercise included basic exercise section and dual-task stepping exercise |
Coppe et al. (2012), Pichierri, Murer et al. (2012) investigated obviously the same intervention program, comprising a 12-week cognitive motor exercise program with progressive strength and balance training and supplemented with additional dance video gaming. Studies differ in measurement systems that were used, as well as the interventions applied to the control group. While the control group in the study of Pichierri, Murer et al. (2012) completed the same program as the intervention group except of dance video gaming, no intervention was applied to the control group in the study conducted by Pichierri, Coppe et al. (2012). While Pichierri, Coppe et al. (2012) and Pichierri, Murer et al. (2012) combined a dance video game with traditional strength and balance training, Schoene et al. (2013) investigated a video game training exclusively. Here, the authors found a significant improvement in the intervention group compared to controls (regarding choice stepping reaction time, physiological profile assessment, postural sway, and contrast sensitivity). Other components (strength and balance training), also integrated in the studies of Pichierri, Coppe et al. (2012) and Pichierri, Murer et al. (2012), were further investigated in a study with a combined cognitive motor intervention without video game (Hiyamizu et al., 2012). As well, the intervention program studied by Uemura et al. (2012) was based on strength training with additional stretching and agility components. Similar to Hiyamizu et al. (2012), motor tasks were combined with additional cognitive tasks. While Uemura et al. (2012) reported significant changes in walking time (under dual-task), COP displacement, and reaction time, people assigned to the intervention group in the study of Hiyamizu et al. (2012) reached significant improvement only in the rate of stroop task.

Up to now, the considered dual-task interventions that have been based on balance components have mostly integrated isolated tasks with no direct references to everyday life. In contrast, Halvarsson et al. (2011, 2013) investigated a dual-task balance exercise training focusing elements based on activities of daily living. Here, short-term effects were reported by Halvarsson et al. (2011), whereas the study by Halvarsson et al. (2013) investigated effects in a long-term determination. Significant improvements were reported in numerous gait parameters (in both single and dual-task walking) both subsequently to the intervention (Halvarsson et al., 2011) and in the nine-month follow-up (Halvarsson et al., 2013). Regarding the 15-month follow-up, a significant improvement was only reported in the self-perceived fear of falling; however, gait speed remained significantly higher in the training group compared to the control group (Halvarsson et al., 2013).

Another form of combining classic exercise components in a dual-task setting was investigated by Yamada, Aoyama, Hikita et al. (2011), Yamada, Aoyama, Tanaka et al. (2011). Here, classic exercises (balance, strength, aerobic) were combined with dual-task seated stepping exercises in a DVD group training (Yamada, Aoyama, Hikita et al., 2011) and a conventional group training (Yamada, Aoyama, Tanaka et al., 2011). While the training group in the DVD group training received a significant improvement only in the dual-task walking time and dual-task time lag, the conventional group training reported significant changes in numerous gait parameters (i.e. cadence, speed, and cost) under cognitive and manual task conditions with an additional improvement in performing the cognitive task. Furthermore, an improvement in the cognitive component during dual-task training was reported by You et al. (2009). Participants were trained with combined walking and cognitive exercises over a six-week period. Although a main component of the intervention was walking exercises, there were no significant changes in gait parameters. Instead of this, Trombetti et al. (2011) reported significant changes in gait parameters under single- and dual-task conditions. Here, community-dwelling individuals older than 65 years participated in a music-based rhythmic training program. The intervention program is based on various multi-task exercises (walking, handling of objects, balance, and/or upper body movements) performed to the rhythm of piano music. Besides the gait changes, the intervention group showed significant fewer falls and a lower risk of falling, as well as significant changes in parameters of balance (i.e. displacement A-P, angular velocity A-P, and/or duration).

The relevant aspects of considered studies investigating dual-task exercises in order to improve gait and/or postural control in healthy older adults could be summarized as follows.
• Treatment durations ranged from four weeks (e.g. Plummer-D’Amato et al., 2012) to six months (e.g. Trombetti et al., 2011).

• The effect of intervention was measured in all studies immediately after the last treatment session. One study reported a long-term follow-up with a retention period of 6 months (Trombetti et al., 2011), another one with 9 or 15 months (Halvarsson et al., 2013).

• Regarding the outcome measures, 14 studies used a combination of clinical assessments and biomechanical analyses of gait or postural control (Granacher et al., 2010; Halvarsson et al., 2011, 2013; Hiyamizu et al., 2012; Li et al., 2010; Melzer & Oddsson, 2013; Pichierri, Murer et al., 2012; Plummer-D’Amato et al., 2012; Schoene et al., 2013; Silsupadol, Shumway-Cook et al., 2009; Trombetti et al., 2011; Yamada, Aoyama, Hikita et al., 2011; Yamada, Aoyama, Tanaka et al., 2011; You et al., 2009). Only three studies applied tools of gait analyses exclusively (Pichierri, Coppe et al., 2012; Silsupadol, Lugade et al., 2009; Uemura et al., 2012).

• Approximately, 130 parameters (spatio-temporal gait parameter, parameters of the center of pressure, etc.) out of the 17 illustrated studies presented significant changes immediately after the intervention, as well as the two investigations with follow-up period regarding gait, postural control/balance, and falls. However, with respect to informative values, it is obvious that these parameters comprise very different aspects of the underlying physiological processes.

3. Discussion

Movement is ubiquitous in human behavior. While individually perceived as simple and automated single-task processes, neurophysiological findings, however, demonstrate the hidden complex structure of daily single-task movements (e.g. walking or standing). Postural control, for instance, as one of the most common requirements in everyday life involves complex processes that require dynamic integration of visual, proprioceptive, and vestibular sensory information (Massion, 1994; Mergner & Rosemeier, 1998). This problem becomes amplified during the process of aging. Zwergal et al. (2012) reported an age-associated shift from automatic (subcortical level) to attentional control (cortical level) of locomotion and stance in elderly people. Therefore, it is likely that with the process of aging, influence in brain functions between locomotion and a conscious secondary task increases. In this conjunction, evidence has been accumulated directly (Annweiler et al., 2013) and indirectly (Lajoie, Teasdale, Bard, & Fleury, 1996). To counteract these processes, training seems to be an efficient method (Wollesen & Voelcker-Rehage, 2013).

But does the dual-task paradigm have the potential of increasing the performance of daily tasks such as postural control and gait?

The present review shows highly consistent results as far as approximately 130 parameters were identified out of all investigated dual-task intervention studies indicating significant improvements related to postural control, gait, falls, or the performance of a secondary task. On the one hand, this manifests the importance of dual-task training. On the other hand, 14 interventions summarized in eight categories from the 17 studies represent a heterogeneous structure. The included interventions characterized by both the exclusive application of motor (Granacher et al., 2010) or cognitive (Li et al., 2010) tasks, as well as a combination of both forms (Halvarsson et al., 2011, 2013; Hiyamizu et al., 2012; Li et al., 2010; Melzer & Oddsson, 2013; Pichierri, Coppe et al., 2012; Pichierri, Murer et al., 2012; Plummer-D’Amato et al., 2012; Schoene et al., 2013; Silsupadol, Lugade et al., 2009; Silsupadol, Shumway-Cook et al., 2009; Trombetti et al., 2011; Uemura et al., 2012; Yamada, Aoyama, Hikita et al., 2011; Yamada, Aoyama, Tanaka et al., 2011; You et al., 2009). Hereby, it is assumed that the interference in context of the dual-task paradigm depends on the similarity or confusability of the mental representations involved in each task (Navon & Miller, 1987). The intervention evaluated by Trombetti et al. (2011) appeared to be unique. Combining motor tasks with changing rhythms, it could be speculated that the implied music supports the automated process of walking. It has been shown that healthy older adults walked faster in time to music and exhibited no changes in spatio-temporal variability (Wittwer, Webster, & Hill, 2013). Regarding automatism, some aspects need to be emphasized. Practicing dual-task (Ruthruff, Johnston, & Van Selst, 2001) or combining relatively
simple or automated processes (Riby, Perfect, & Stoller, 2004) leads to the same effect: reduced central interference in dual-tasking. It can be assumed that a decline of variability of the concurrent secondary task during training also leads to a reduced interference. Therefore, seated stepping exercises (Yamada, Aoyama, Hikita et al., 2011, Yamada, Aoyama, Tanaka et al., 2011) might tend to be an automated process compared to others which are characterized by a more ambitious context.

The integration of new technology such as video games (Pichieri, Coppe et al., 2012, Pichieri, Murer et al., 2012; Schoene et al., 2013) and computer programs (Li et al., 2010) into training might have the potential of overcoming many of the current barriers to physical activity (Biddiss & Irwin, 2010; Jorgensen, Laessoe, Hendriksen, Nielsen, & Aagaard, 2012). On the one hand, different aspects such as motivational effects, as well as the independence of the application, the standardization, and high variability, promote these new technologies. On the other hand, especially these aspects may lead to the risk of an exclusive consideration of the “effect” of an intervention without displaying attention to the “original stimulus” of combined tasks. Within dual-task, it seems to be a general problem to focus exclusively on the effects in terms of physiological output parameters rather than investigating the original stimulus. In the present review, this phenomenon is reflected in the lack of applying specific stimuli in the interventions, despite showing consistently significant results. However, to obtain optimal output parameters, it is necessary to examine the internal processes of the stimulus. In this context, the theories of dual-tasking (capacity sharing, bottleneck, and/or crosstalk) and further hybrid forms commonly have been used to describe the interference of internal central processes (Pashler & Johnston, 1998). Beside these theoretical constructs, imaging studies provide the opportunity of gaining an understanding of the localization of dual-task processes. However, a consideration of the individual task and its systematization with respect to brain imaging hardly seems to be possible (Takeuchi et al., 2013). But in order to optimize the use of dual-tasking, a systematization of underlying parts is inevitable. To ensure this systematization, conclusions from the effect of the stimulus have to be drawn. To obtain such a pattern, in future research, a gradual augmentation of task complexity has to be pursued. One approach could be to vary sensory modalities of the secondary task and to keep the primary motor task constant (Liebherr et al., 2015). Henceforth, a further comparison between different age groups is necessary to get an insight into the alterations of dual-task processability with aging.

Further research should be conducted with regard to the remarks of the present review.

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