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Specific transfer effects following variable priority dual-task training in older adults

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Abstract.
Purpose: Past divided attention training studies in older adults have suggested that variable priority training (VPT) tends to show larger improvement than fixed priority training (FPT). However, it remains unclear whether VPT leads to larger transfer effects.
Methods: In this study, eighty-three older adults aged between 55 and 65 received five 1-hour sessions of VPT, FPT or of an active placebo. VPT and FPT subjects trained on a complex dual-task condition with variable stimulus timings in order to promote more flexible and self-guided strategies with regard to attentional priority devoted to the concurrent tasks. Real-time individualized feedback was provided to encourage improvement. The active placebo group attended computer classes. Near and far modality transfer tasks were used to assess the generalization of transfer effects.
Results: Results showed that VPT induced significantly larger transfer effects than FPT on a near modality transfer task. Evidence for larger transfer effects in VPT than FPT on a far modality transfer task was also observed. Furthermore, the superiority of VPT on FPT in transfer effects was specific to the ability to coordinate two concurrent tasks.
Conclusions: Results of this study help better understand the benefits of VPT attentional training on transfer effects, which is an essential outcome for cognitive training effectiveness and relevancy.

Keywords: Cognitive training, transfer, divided attention, variable priority training, older adults

In the past few years, a wide range of studies have observed that cognitive training leads to training-specific improvements in older adults (Karbach & Schubert, 2013; Lovden et al., 2010). Cognitive training is thought to challenge an individual's cognitive abilities and to lead to additional recruitment of cognitive resources rarely used in daily life. Both younger and older adults seem to respond to a cognitive challenge with structural changes such as reorganization in task-relevant brain areas (Lindenberger, 2014; Park & Reuter-Lorenz, 2009). However, the extent to which new learning leads to benefits in a novel situation (transfer effects) remains a matter of debate (Green & Bavelier, 2008; Willis & Schaie, 2009). From a clinical standpoint, transfer effects are mandatory if cognitive training is to be used as a tool to maintain and enhance cognitive functions in older adults' daily activities. Still, research is needed to further our understanding of fundamental mechanisms of transfer. One should aim to unveil training aspects that play a critical role in enhancing transfer effects, as design choices can impact substantially on cognitive training outcomes (Lampit, Hallock, & Valenzuela, 2014). Green & Bavelier (2008) suggested that variation in learning experience is a key element to optimize transfer effects. However, empirical support for this is still lacking. Several studies have looked at the potential benefit of variable strategy training in the realm of attention and attentional control training. In a variable priority

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training (VPT) procedure, participants are required to vary attentional priority between two concurrent tasks, as opposed to a more typical fixed priority training (FPT), in which attention is equally shared between tasks.

A few studies have shown that divided attention training leads to larger performance gains with a VPT procedure than with FPT (Bier, de Boysson, & Belleville, 2014; Kramer, Larish, & Strayer, 1995; Kramer, Larish, Weber, & Bardell, 1999; Lee et al., 2012; Silsupadol et al., 2009). Yet, whether the VPT procedure leads to larger and broader transfer effects deserves further inquiry. The goals of this study were to investigate the benefits of variable priority strategy in divided attention training and to assess whether it leads to larger transfer effects than fixed priority training in older adults.

There is no consensus on the mechanisms underlying the advantage of VPT over FPT. According to Cassavaugh & Kramer (2009), training individuals to successfully shift priorities among tasks help them emphasize the relationships between different task components. Allocating attentional priority is a crucial attention control skill when performing several tasks. Also, individuals can focus on a specific component of the task while considering the general context of it, thereby reducing processing demands encountered during initial learning. Gopher (2007) also suggests that training cognitive processes in a rapid complex task with multiple attentional demands (e.g., driving) produces better learning if the training involves variable emphasis on different task components rather than training on individual components in blocked presentations. Finally, VPT might lead to more benefits than FPT simply by encouraging participants to pursue different ways to perform a task, leading to more efficient learning (Schmidt & Bjork, 1992). Overall, VPT seems to call upon the ability to control and distribute attention and may play an important role in further enhancing dual-task coordination skills.

In a set of studies comparing VPT and FPT in dual-task performances (Kramer et al., 1995; Kramer et al., 1999), younger and older adults were trained to monitor several gauges and to simultaneously perform a 1-back task based on judgment of alphanumeric problems. Individualized adaptive feedback was provided continuously to the participants in order to ensure that task prioritization instructions were followed. Though both groups did improve through training, VPT led to accelerated learning of the task and to a larger magnitude of improvement in accuracy and processing speed on the trained task. In another study, Silsupadol et al. (2009) trained participants aged 65 and older to walk between two strips of tape while counting backward by 3 s. Results showed that participants who received VPT improved to a greater extent than those trained in a more typical FPT. Similarly, Boot et al. (2010) showed that in younger adults extensive (20 hrs) VPT with the complex video game Space Fortress (Donchin, 1989) led to 28% better performance than FPT. Also, participants from the VPT group reached the final performance of the FPT group in half the time. More recently, Bier et al. (2014) trained healthy older adults on a dual-task condition combining a visual detection task (pressing the space-bar when presented with a red rectangle) and judging an alphanumeric equation. Here again, VPT produced greater improvements on the trained dual-tasks than FPT.

The studies reported so far tend to suggest that VPT leads to larger training-specific improvements and sometimes steeper learning curves than FPT. However, in a set of studies, Bherer et al. (2005, 2008) compared VPT to FPT using dual-tasks composed of two very simple 2-choice discrimination tasks (e.g., identifying letters or numbers appearing on the screen). In the dual-task paradigm they used, there were three different trial types: in single-pure (SP) trials, participants respond to one stimulus of a single task-set; in single-mixed (SM) trials, participants respond to a single stimulus of either task-set; in dual-mixed (DM) trials, participants respond to two simultaneous stimuli, one of each task-set. Comparing performances in the three trial types provides important insight on how concurrent tasks can be performed. In fact, SP and SM trials of a given task require similar responses but are performed in different contexts. Thus, the difference in response time (RT) between SP and SM trials provides a task-set cost assumed to reflect the ability to maintain many response alternatives in memory and to prepare to answer to multiple tasks. A second performance index, the dual-task cost, can be observed by comparing RTs in SM trials and DM trials. Both trials are performed in a context involving two concurrent tasks, but only DM trials actually require monitoring the two tasks simultaneously and not sequentially. Dual-task cost is thought to reflect the additional cost due to the synchronization of two concurrent tasks (Bherer et al., 2005; Schumacher et al., 2001). Results from Bherer et al. (2005, 2008) indicated that improvement in divided attention abilities was observed in both VPT and FPT groups, as shown by a decrease in dual-task cost, but that there was no additional benefit for the VPT group compared to the FPT group. The authors argue that the superiority of VPT over FPT may only be observed under complex task coordination and that simple tasks may not lead to the development of sophisticated task coordination strategies.

Another major issue is whether VPT leads to larger and/or broader transfer effects. Transfer effects are important to ensure that cognitive training leads to more than task-specific learning and potentially generalizes to everyday life benefits (Dahlin et al., 2008). Transfer effects would also suggest that cognitive training improved the cognitive ability, over and beyond task-specific learning (Lindenberger, 2014). According to Zelinski (2009), transfer can be described as near or far, depending on the distance between the training and the transfer conditions. Overall, findings on transfer effects following cognitive training are relatively narrow (Melby-Lervag & Hulme, (2013) for a review). However, several dual-task training studies have shown promising evidence of near and far transfer effects after executive function computerized training with tasks using different sensory modalities or motor responses than the ones used for training (i.e., modality transfer) (Klingberg, 2010; Kueider, Parisi, Gross, & Rebok, 2012; Lustig, Shah, Seidler, & Reuter-Lorenz, 2009). It is not clear whether VPT leads to larger transfer effects than FTP. Studies have reported transfer effects after dual-task FPT (Li et al., 2010; Lussier, Gagnon, & Bherer, 2012) and no advantage of VPT over FTP (Bherer et al., 2005, 2008; Lee et al., 2012). Others studies, however, have observed that VPT is more likely to induce modality transfer effects than FPT (Boot et al., 2010; Kramer et al., 1995; Kramer et al., 1999).

Overall, it seems that VPT tends to show larger improvement than FPT in some studies, but the extent to which this advantage transfers to untrained tasks has not been strongly established in the literature. The goal of the present study was to assess the superiority of VPT over FPT in transfer effects. We used dual-tasks similar to those from previous studies (Bherer et al., 2008; Lussier et al., 2012), but with time-independent tasks, in order to favor a more flexible and self-guided strategy in terms of attentional priority devoted to the concurrent tasks. According to Noack, Lovden, & Schmiedek (2014), transfer effects should be confined to the cognitive process targeted by the cognitive training. Therefore, in accordance with Kramer et al. (1999), we hypothesized that VPT would specifically improve abilities related to attentional control required to coordinate multiple response-stimulus alternatives. Therefore, the present study assessed near modality and far modality transfer effects in dual-task cost and task-set cost following VPT and FPT. We expected that VPT would lead to larger improvements than FPT, but only for the coordination of multiple alternatives (dual-task cost), and not in cognitive components non- specific to VPT such as working memory (task-set cost) and general psychomotor speed.

1. Method

1.1. Participants

Community-dwelling adults aged between 55 and 65 were recruited from newspaper ads, the laboratory website, flyers posted in community centers and libraries, as well as from the study research center's participant pool. Exclusion criteria for the phone screening were a history of a neurological condition, a major surgery in the last 6 months, use of medication known to affect cognition (e.g., antidepressant or anxiolytic) or a body mass index (BMI) under 18.5 or over 30 (i.e., in the obese range using U.S. DHHS definitions). Participants selected for the pre-training evaluation were screened for cognitive impairment (excluded if scored lower than 27 on the Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975)) or depression (excluded if scored higher than 20 on the 30-items Geriatric Depression Scale (Yesavage, 1988)), but no participant exceeded these criteria. Participants received a financial compensation (10 CAD/hour for a total of 90 CAD). The study was approved by the Ethics Review Board of the geriatric institution where the study took place and all participants provided written informed consent.

The active placebo cognitive stimulation consisted of a course taught to groups of 4 to 10 persons. Therefore, the cognitive training was also performed in a group format rather than individually to better control for possible social interactions. This approach was also used in previous studies from our group (Castonguay et al., 2015; Li et al., 2010). Group training can also reduce experimental costs and raise motivation in participants. In that sense, different studies suggest that social interaction may be an important factor in cognitive training (see Cook and Black, 2012 for a review in schizophrenia). Participant's assignment was done by wave randomization. When a group of about ten eligible participants were recruited, they were randomly assigned to the cognitive training group or to the placebo cognitive stimulation group according to a block randomization plan generated via a website (www.randomization.com). Since training was performed in groups of 4 to 10 persons, participants from the same cohort could not be randomly assigned to VPT or FPT without compromising participants' blindness to the existence of another training group. Hence, the type of training (VPT or FPT) was the same for all participants of a given wave.

Of the initially assigned 88 participants, five could not complete the protocol due to unforeseen events. In order to compare the efficacy of dual-task training to a stimulating non-specific intervention, 38 were assigned to the placebo cognitive stimulation group and 45 to the training groups. Then, to be able to compare the efficacy of VPT and FPT, the training group was further divided in two groups (27 completed the VPT and 18 completed the FPT). Table 1 presents participants' characteristics. The neuropsychological assessment involved tests of general verbal abilities (Similarities, WAIS-III), processing speed (Digit Symbol, WAIS-III, X-O comparison), working memory (Digit Span, WAIS-III), episodic memory (Rey Auditory Verbal Learning Test), executive functions (Baddeley dual-task (Della Sala et al., 1995)), Stroop Color-Word Interference Test (D-KEFS (Delis, Kaplan, & Kramer, 2001)), two-back task (Lezak & Lezak, 2012), and number-letter task (Rogers, 1995).

1.2. Apparatus

Participants performed the dual-task paradigm in a dedicated computer room, in groups of 4 to10 persons, each individual using a PC Pentium 4 with a 19" flat screen in a cubicle. Each participant used the same computer throughout the whole study protocol.

The dual-task paradigm involved performing two discrimination tasks alone or concurrently. Three different dual-task conditions were used: the training condition, the near modality transfer condition and the far modality transfer condition (see Fig. 1 for summary). For the training condition, participants had to perform a digit discrimination task (3, 5 or 8) by pressing the letters A, S or D on the keyboard with their left hand, and/or a shape discrimination task (circle, square or diamond) by pressing the numbers 4, 8 or 6 on the numeric keypad with their right hand. The numbers were presented inside the shapes. Participants responded with their index, middle and ring fingers using their left or right hand. With the same response-mapping, the near modality transfer condition required participants to identify letters (A, B or C) and arrows (left, right or up). Stimuli were arranged vertically. Visual stimuli appeared in white in the middle of a black screen at a viewing distance of approximately 45 cm. At this distance, stimuli subtended a vertical and a horizontal visual angle of 3.17°. Visual stimuli remained on the screen until the participant provided a response. The far modality transfer condition consisted of a sound identification task (words "GO" or "STOP") and a lateralization task (determine if a tone was heard on the left or right side of the headphones). Only two response alternatives were used for the auditory task (using only keys A, S, 4 and 8) in order to reduce the gap in task-set cost usually observed at pre-training between visual and auditory tasks (Lussier et al., 2012). Participants wore headphones and could adjust the volume if needed. Auditory stimuli was heard during 500 ms. No feedback was given in the case of an error in the auditory task (e.g., no buzzer sound).

1.3. Program schedule

With the exception of the first session, all sessions were conducted in groups of 4 to 10 participants. The research protocol was completed within a 4- to 5-week period and was divided into three phases: pre-training evaluation, training, and post-training evaluation. In the first 2-hour pre-training session, participants individually completed a neuropsychological assessment battery administered by a trained neuropsychology student who was blind to intervention assignations. Then, within two weeks following the first session, all participants engaged in a second 1-hour training session in groups of 2 to 10 participants to complete the two dual-task transfer conditions (visual and auditory). After the two pre-test sessions were completed, participants were assigned to the training or control group. Over a period of 2-3 weeks, both groups completed five 1-h sessions in a room containing 10 computer stations. A psychology student supervised each session. Lastly, participants completed a 1.5-h post-training session within a week following the last training session. During this last session, the two transfer dual-task combinations were administered again in order to assess the transfer effects induced by the training program.

Table 1
Baseline demographic and neuropsychological data

	Fixed priority training $n=18$	Variable priority training $n=27$	Placebo cognitive stimulation $n=38$	F(2, 80) =
Demographics				
Age	61.1 ± 2,7	62.4 ± 2.2	61.2 ± 2.3	2.38, $p=0.10$
Education (yrs)	15.3 ± 2.4	15.4 ± 3.0	15.2 ± 2.4	0.23, $p=0.98$
Gender, *F(M)*	13(5)	19(8)	25(13)	
Body Mass Index	24.2 ± 3.2	24.72 ± 3.1	24.2 ± 3.3	0.24, $p=0.79$
Geriatric Depression Scale	4.9 ± 3.3	3.1 ± 3.4	3.3 ± 3.4	1.66, $p=0.20$
Cognitive screening				
MMSE (score)	29.3 ± 0.8	28.9 ± 1.0	29.1 ± 0.9	1.18, $p=0.31$
Digit Span (score)	17.7 ± 4.7	16.6 ± 4.7	17.1 ± 4.4	0.32, $p=0.73$
Similarities (score)	23.1 ± 4.4	23.4 ± 4.8	22.0 ± 4.1	0.92, $p=0.40$
Symbol (score)	69.7 ± 13.8	69.3 ± 12.1	69.5 ± 11.8	0.01, $p=0.99$
Rey word Recall (total)	52.4 ± 10.9	52.1 ± 6.6	54.6 ± 8.5	0.83, $p=0.44$
Mill Hill (score)	27.9 ± 3.0	27.0 ± 4.9	27.4 ± 2.8	0.34, $p=0.72$
X-O comparison (score)	26.2 ± 5.0	26.0 ± 6.2	27.0 ± 5.2	0.32, $p=0.73$
Stroop inhibition (s)	112.5 ± 31.0	104.4 ± 17.5	112.3 ± 26.8	0.90, $p=0.41$
Stroop switching (s)	134.94 ± 34.4	125.9 ± 21.9	131.5 ± 33.3	0.52, $p=0.60$
Number-letter switching (ratio)	11.6 ± 7.1	11.5 ± 5.2	14.9 ± 9.0	0.09, $p=0.92$
Baddeley index (ratio)	88.94 ± 8.4	90.8 ± 8.7	91.0 ± 9.8	2.11, $p=0.13$

Note: All data are presented: Mean ± standard deviation.

	Schedule	Left hand (A, S, D keys)	Right hand (4, 8, 6 keys)
Training condition	Five 1-h sessions over 2-3 weeks	3 5 8	
Near transfer condition	Two 20-min sessions, 1 prior and 1 after training (both within one week from training)	A B C	
Far transfer condition*		Words "GO" and "STOP"	Bip sounds from left or right

Fig. 1. Summary of training designs. All discrimination tasks were performed either alone or concurrently in their respective conditions. * Only keys S, D, 4 and 8 were used for the far transfer condition. Also note that, in mixed blocks, number appeared within the shape in the training condition.

1.4. Computer training interventions

1.4.1. Training condition

During a training session, task instructions appeared on the screen prior to each novel task step. Participants initiated each block by pressing the spacebar. Subsequent trials appeared after a short variable interval of 850 to 2850 ms. Three different types of blocks were performed. In SP blocks, participants responded to one stimulus of a single task-set at a time. In SM blocks, participants respond to a single stimulus at a time, but the stimulus could be of either task-set. In DM blocks, participants responded to two simultaneous stimuli, one of each task-set, in a time-independent manner: answering one stimulus triggered the next trial of the same task, but did not influence the other task. For all blocks, participants were asked to respond as quickly and as accurately as possible. At all times, a stimulus-response mapping was provided on the left and right at the bottom of the screen as a reminder of stimulus-key association. Accuracy feedback was provided when a wrong answer was given, participants heard a buzzer sound and the stimulus-response mapping associated with the wrong answer appeared in red on the bottom of the screen.

Task instructions were administered by a trained student who did not participate in the pre- or the post-training evaluations. Within each training session, a participant responded to 144 SP, 480 SM and 1080 DM trials, completing 720 SP, 2400 SM and 5400 DM trials in total through the five training sessions. Variables of interest were RT means (in ms) and accuracy (in %). RTs were calculated independently for each discrimination task, from stimulus occurrence to the participant's response. Incorrect responses were not included in the RT means analyses, and trials were also rejected if RT was shorter than 250 ms, longer than 3000 ms for SP and SM trials or longer than 4000 ms for DM trials (near transfer: 1.27% of SP, 0.42% of SM and 1.26 % of DM trials; far transfer: 2.2% of SP, 1.85% of SM and 0.87% of DM trials). Accuracy was calculated as a percentage of correct responses in each condition.

Importantly, a continuous feedback on performance was provided during the DM block of the training sessions (sessions 3 to 7). Feedback took the shape of two changing color bars (green, yellow or red) to inform participants of their response speed. Each bar was associated to one task, therefore to one hand. In order to help participants manage priorities, they were asked to try to maintain the bars in the green zone and prevent them from turning red. The bar color was determined by the average RT on the last three trials of the DM block, compared to the median RT of the SM block multiplied by a factor of 1.5. Hence, an average RT of the three previous DM trials was considered an average performance (yellow) if it equalled to 1.5 X the median RT of the SM block. The bars turned red if the average RT approached twice the SM median RT and turned green if it approached the actual SM mean RT. In addition to this continuous feedback, another type of feedback was provided at the end of each session using a histogram where participants were informed of mean RT and accuracy achieved throughout the session. These two types of feedback were used to maintain participants' motivation during the training.

Finally, for participants assigned to the VPT, instructions varied among DM blocks. On the first and last DM blocks of each training session, participants were instructed to give equal emphasis to both tasks. On the second and fourth DM blocks, they were instructed to prioritize the tasks performed with their left hand. On the third and fifth DM blocks, they were instructed to prioritize the tasks performed with their right hand. To guide participants, the colored bars used for feedback were adjusted to fit the instructed priorities: the median SM factor was changed from 1.5 to 1.25 X for the prioritized task and to 2 X for the non-prioritized task. Participants were informed that task feedback would be more or less strict based on the priorities and they were instructed to aim for green on the prioritized task bar. By contrast, participants in the FPT group were always reminded to give equal emphasis to both tasks in the DM blocks.

1.4.2. Placebo cognitive stimulation

The placebo group was an active group receiving computer classes. Each session consisted of introductory exercises using the computer and different software (e.g., Word, Excel), as well as initiation to the Internet (search engines, web sites, games, etc.). Cognitive stimulation sessions were held in groups of 4 to 10 participants and took place in the same computer room used for dual-task training sessions. This was done in order to minimize unwanted variability between experimental groups. The students supervising the dual-task training were the same who taught the cognitive stimulation sessions for a given cohort.

1.5. Transfer conditions

For near and far modality transfer conditions, participants performed two discrimination tasks, either alone or simultaneously, but the tasks performed differed from the training condition. The near transfer condition involved two visual modality tasks while the far modality condition involved two auditory modality tasks (see Apparatus section). The procedure was very similar to the training condition except for a few differences. The transfer conditions were shorter in time and involved fewer trials: 96 SP, 192 SM and 120 DM. Also, all participants were always asked to give equal priority to both tasks in DM blocks during transfer conditions. Finally, no feedback was provided for speed in the transfer conditions.

1.6. Statistical analysis

Statistical analyses were run with SPSS 20. First, ANOVAs were performed on demographic and neuropsychological data to ensure the three groups were comparable in age, gender, school years, and cognitive abilities prior to training (see Table 1). Then, analyses were performed on RT means and accuracy means using mixed-model ANOVAs for each of the three dual-task conditions (training, far modality transfer, and near modality transfer). For the training, the main analysis sought to examine was if VPT lead to a larger magnitude of improvement or a faster learning curve than FPT. To do so, only the two blocks for which the VPT group received equal priority instruction (first and last DM blocks) were compared. An ANOVA was performed with Training group (FPT vs. VPT) as the between-subject factor and Session (first to fifth), Task (right vs left hand), and Trial type (SP, SM, DM) as within-subject factors. To assess modality transfer effects, two sets of analyses were performed, one for each of the transfer conditions: near modality transfer condition (visual) and far modality transfer condition (auditory). The ANOVA model was similar to the one used for training, with Training group (FPT, VPT, placebo cognitive stimulation) as between-subject factor, and Session, Task, and Trial type as within-subject factors.

An effect was reported as significant according to the sphericity-assumed alpha level ($p < 0.05$). However, when the assumption of sphericity was violated (significant Mauchly's test), we reported the Greenhouse-Geisser corrected degrees of freedom. Effect sizes ($\eta 2$) were also reported. In case of significant Training group interactions, each group were compared between with one another. Also, in the case of a significant interaction with more than two levels of a repeated-factor, repeated-contrasts were used.

For each of the three dual-task conditions (training, far modality transfer, and near modality transfer), there was no Session X Task interaction Thus, performances of the 2 tasks were pooled for each condition. Moreover, in terms of accuracy, there was no group difference, it did not vary during training, and neither did it change in the transfer conditions from pre- to post-training. Accuracy was arguably high prior to training in the visual dual-task condition (SP: 98%, SM: 99%, DM: 98%) and in the auditory dual-task condition (SP: 97%, SM: 95%, DM: 91%). In all likelihood, due to a ceiling effect, no significant improvement of accuracy was observed from pre- to post-training. Therefore, the following analyses reported variations in average RTs only.

2. Results

2.1. Demographic and neuropsychological data

ANOVAs were performed on demographic and neuropsychological data. Assumption of homogeneity of variance (Levene's test) was respected for each comparison and results showed that the three groups were comparable on all measures (see Table 1).

2.2. Training condition

Prior to the main analyses, it had to be demonstrated that participants from the VPT and FPT groups had followed the priorities as instructed by the program. To do so, ANOVAs were performed with Session (first to fifth) and Priority (equal priority condition, prioritized tasks, non-prioritized tasks for the VPT and corresponding blocks for the FPT) in each training group. In the VPT, results revealed a significant effect of Priority, $F(2, 52) = 22.26$, $p < 0.001$, $\eta^2 = 0.46$, suggesting that RTs varied depending on the priority instructions. RTs were faster in prioritized tasks than in equal priority tasks, $F(1, 26) = 21.75$, $p < 0.001$, $\eta^2 = 0.46$, and faster in equal priority tasks than in non-prioritized tasks, $F(1, 26) = 4.66$, $p < 0.05$, $\eta^2 = 0.15$, as shown in Fig. 2. In the FPT group, no significant effect of Priority was observed, $p > 0.05$, which suggests that participants gave equal priority to both tasks. Therefore, results show that participants in each group adequately followed the instructions.

The main analysis sought to examine whether the VPT either lead to a larger magnitude of improvement or a faster learning curve than the FPT. A main effect of Session, $F(1.87, 81.09) = 122.43$, $p < 0.001$, $\eta^2 = 0.74$, indicated that RT decreased with training. Repeated-contrasts showed that RT significantly decreased between each consecutive training session (ps < 0.05). Moreover, this effect was qualified by a Session X Trial type interaction, $F(2.86, 122{,}98) = 21.38, p < 0.001, \eta^2 = 0.33$. Indeed, repeated-contrasts revealed significant improvements of dual-task cost between each session, respectively $F(1{,}43) = 7.55$, 9.58, 7.47, 13.71, ps < 0.01, $\eta^2 = 0.15$, 0.18, 0.15, 24 (see Fig. 3). Importantly, the Training group X Session interaction did not reach significance, $F(2.86, 122.98)$. This suggests that improvement was equivalent in both VPT and FPT. Figure 2 shows the average RT (panel 1), and dual-task cost and task-set cost (panel 2) in the 5 training sessions.

2.3. Transfer conditions analyses

2.3.1. Near modality transfer condition

A Training X Session interaction was observed, $F(2, 80) = 5.59$, $p = 0.05$, $\eta^2 = 0.12$, as well as a Training X Session X Trial type interaction, $F(2.35, 94.09) = 4.10$, $p < 0.05$, $\eta^2 = 0.09$, suggesting that training programs impacted task-set cost and/or dual-task cost in different manners. Repeated-contrasts showed that transfer effects among groups only differed for dual-task-cost, $F(2, 80) = 3.08$, $p < 0.05$, $\eta^2 = 0.07$, and not for task-set cost. Figure 4 shows dual-task and task-set costs in the pre- and post-training sessions. Simple-effect analyses indicated that dual-task cost improvement was significant in all

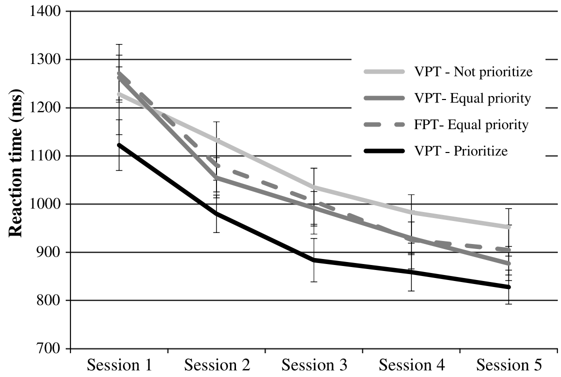

Fig. 2. Comparison of participant's mean reaction time, based on priorities instructions, on dual-mixed trials during the variable priority training. Bars represent standard error. VPT: variable priority training, FPT: Fixed priority training.

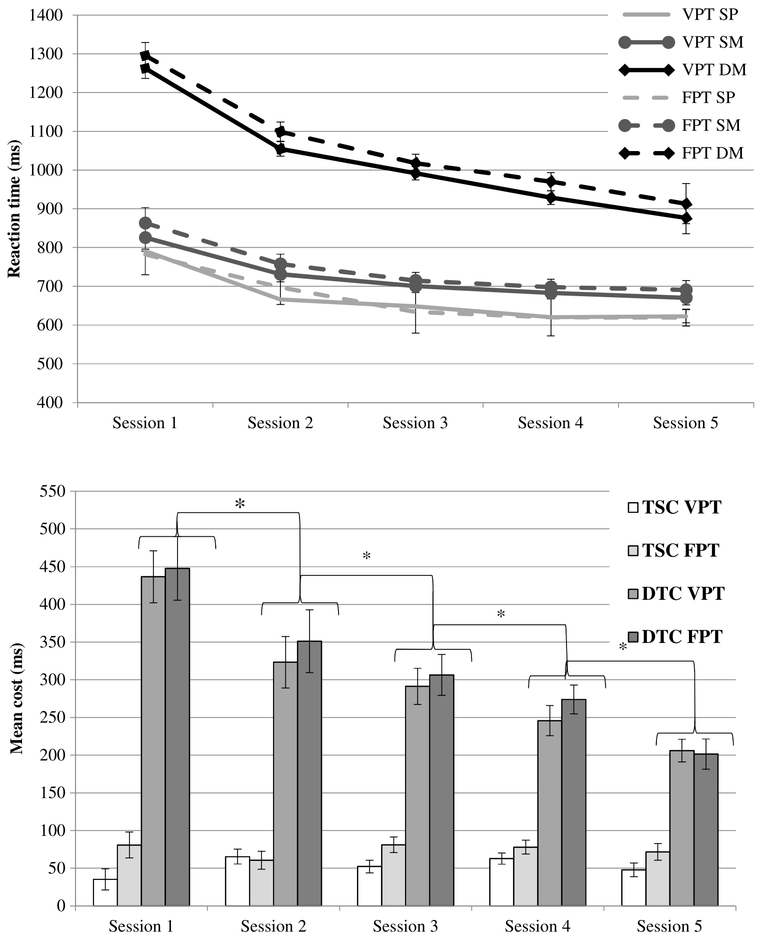

Fig. 3. Mean reaction time (top panel) and costs (bottom panel) on the five sessions of training for variable priority training and fixed priority training. SP: Single-pure trials, SM: Single-mixed trials, DM: Dual-mixed trials, TSC : task-set cost, DTC : dual-task cost. Bars represent standard error. Asterisks indicate significant improvement from pre-test to post-test.

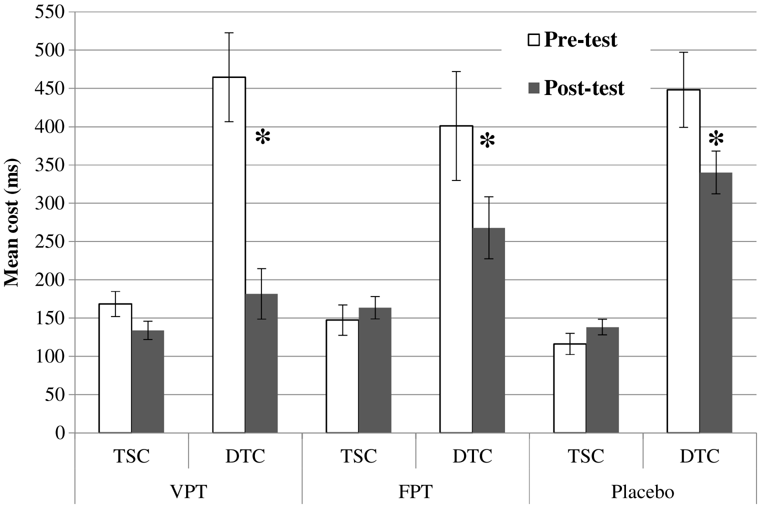

Fig. 4. Mean costs on the near modality transfer task (visual) for variable priority training (VPT) and fixed priority training (FPT) and placebo cognitive stimulation. TSC: task-set cost, DTC: dual-task cost. Bars represent standard error. Asterisks indicate significant improvement from pre-test to post-test.

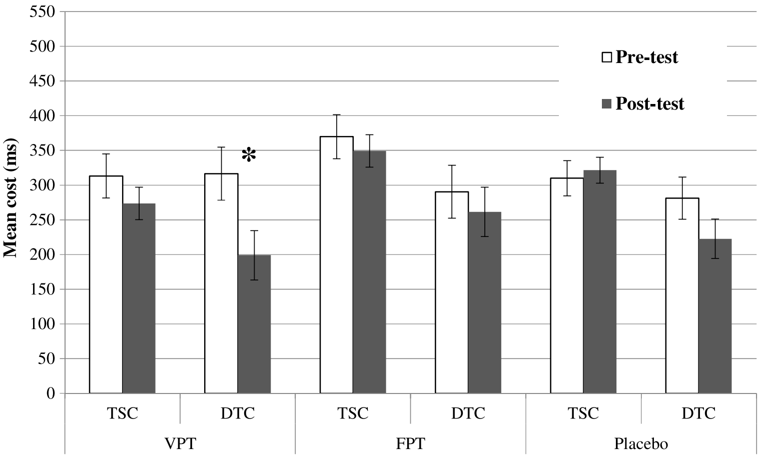

Fig. 5. Mean costs on the far modality transfer task (auditory) for variable priority training (VPT) and fixed priority training (FPT) and placebo cognitive stimulation. TSC: task-set cost, DTC: dual-task cost. Bars represent standard error. Asterisks indicate significant improvement from pre-test to post-test.

training groups, though greatly superior in the VPT (VPT: 283 ms, $F(1, 26) = 29.05$, $p < 0.001$, $\eta^2 = 0.53$, FPT: 132 ms, $F(1, 17) = 6.84$, $p < 0.05$, $\eta^2 = 0.29$, active placebo: 108 ms, $F(1, 37) = 4.15$, $p < 0.05$, $\eta^2 = 0.10$). When contrasted between groups, improvement in dual-task cost was larger in the VPT compared to the active placebo group, $F(1, 63) = 5.15$, $p < 0.08$, $\eta^2 = 0.07$, and VPT compared to FPT, $F(1, 43) = 3.84$, $p < 0.05$, $\eta^2 = 0.07$, but equivalent between FPT and active placebo ($p < 0.05$).

2.3.2. *Far modality transfer condition*

Three subjects refused to perform the auditory dual-task condition due to diagnosed auditory impairment and one participant was excluded from our analyses because of technical difficulties with the headset. In addition, four participants had more difficulties than anticipated localizing the sound (left or right) and were excluded for not being able to answer in time and correctly to more than 30% of each trial type for that specific task at pre-training. In the end, 35 participants from the placebo cognitive stimulation group, 23 from the VPT group and 17 from the FPT group completed the modality transfer condition.

Results showed a significant Training X Session interaction, $F(2, 72) = 2.99$, $p < 0.05$, $\eta^2 = 0.08$, indicating that transfer effects differed among intervention groups. Indeed, VPT (109 ms) showed a significantly larger overall improvement when compared to the active placebo group (33 ms), $F(1, 56) = 7.41$, $p < 0.01$, $\eta^2 = 0.12$. Overall, transfer effects in the FPT group (57 ms) were not different than the ones observed in the active placebo group. Cost analyses showed that dual-task cost improved in the VPT group (117 ms), $F(1, 22) = 6.23$, $p < 0.05$, $\eta^2 = 0.22$, but not in the FPT (28 ms) and active placebo (57 ms) groups. Figure 5 shows dual-task and task-set costs in the pre- and post-training sessions.

3. Discussion

We conducted a dual-task training study to examine the benefits of VPT over FPT and a placebo condition on the acquisition of dual-task coordination skills in older adults. Our main focus was on transfer effects, which have often been associated with improvement in executive control skills, as opposed to proceduralization of a specific stimulus-response mapping. Near and far modality transfer conditions (respectively within- and cross-modality) were assessed in order to test whether coordination skills acquired through training would generalize to untrained tasks.

In line with previous studies, individualized adaptive feedback encouraging participants to follow priorities was provided. Indeed, the ability to concurrently perform multiple tasks and to shift priorities might only be developed when participants are explicitly trained to do so (Bherer et al., 2005, 2008; Green & Bavelier, 2008; Kramer et al., 1995; Kramer et al., 1999; Lussier et al., 2012). The training procedure used in the present study was similar to the one used in previous studies (Bherer et al., 2008; Lussier et al., 2012), but a particularity of the present study was the use of time-independent tasks, which was expected to make the task more demanding and more conducive to flexible strategies. Performances of the training groups were compared to those of a cognitive stimulation group in order to better assess specific effects of cognitive training. Before conducting main analyses, we ensured that participants from the VPT and FPT groups had followed the priorities as instructed. Failure to do so would have limited any conclusion concerning VPT and FPT comparison. Such verification was often lacking in previous studies and should always be done in future priority-training studies. As expected, the VPT group had changed their response patterns based on the instructions while FPT response patterns remained unchanged.

To assess the specificity of transfer effects, two measures were analyzed: task-set cost, a measure of the capacity to prepare for and maintain multiple task sets, and dual-task cost, a measure of the capacity to perceive multiple stimuli and coordinate the execution of two responses. We observed comparable task-set cost reductions for VPT and FPT. However, dual-task cost reduction was significantly larger following VPT than FPT or placebo cognitive stimulation. This suggests that learning to vary attentional priorities during dual-task training leads to a larger transfer effect than fixed priority training, but that this effect is specific to the ability to coordinate two concurrent tasks. With regard to far modality transfer conditions, only VPT led to a greater overall transfer effect when compared to cognitive stimulation control. Interestingly, separate analyses for cost-related transfer effects showed that only the VPT led to a significant decrease of dual-tasks costs. Yet, the difference in cost-related transfer between VPT and FPT did not reach significance. Therefore, we observed modest benefits of VPT on far modality transfer; though there is evidence that VPT represented the most potent intervention. Overall, as expected, VPT led to larger transfer effects than FPT and transfer effects were specific to the ability to coordinate multiple concurrent responses. There was no evidence for speed-accuracy trade-off as no change in accuracy was observed in response to training.

The present study is highly relevant to the field of cognitive aging as evidence that VPT could lead to larger transfer effects was lacking. In Kramer et al. (1995; 1999), the transfer and the training tasks were combinations of visuo-motor monitoring tasks and working memory tasks. They observed that individuals who were assigned to the VPT were better on a near modality transfer task than those who did the FPT. Importantly, VPT training benefits were larger in the dual-task condition than in the single task condition for both the training and the transfer tasks. However, performances were not evaluated prior to training which limits the conclusions. In Boot et al. (2010), participants were assessed on several untrained tasks both prior and after training on Space

Fortress. Results showed larger transfer following VPT on the transfer tasks most analogous to Space Fortress. However, with a similar protocol and the inclusion of a control group, Lee et al. (2012) failed to replicate these results.

Moreover, the present studies used time-independent tasks, as most studies observing advantages for VPT over FPT used time-independent tasks (Bier et al., 2014; Boot et al., 2010; Kramer et al., 1995; Kramer et al., 1999; Silsupadol et al., 2009). Time-independent tasks are performed in parallel, which means that answering to one task triggers the next trial of that specific task, but does not influence the other task. Time-independent tasks might have allowed for more ambiguous decisions in VPT, such as when the prioritized stimulus appears shortly after the unprioritized one. This uncertainty about the delay between stimulus appearances may prevent the response patterns' automatization and may impose more challenge in terms of attention control. Most studies which did not observe advantages of VPT over FPT used time-dependent tasks (e.g., Bherer et al., 2005; 2008). This could indicate that time-independent tasks are an important component in order for the VPT benefits to take place.

Surprisingly, in the present study, the superiority of VPT over FTP was only observed in transfer conditions: both groups reached similar magnitudes of training-specific improvement. During training, the VPT group's learning curves were not steeper and by the end of the training, participants in VPT group did not produce better performances than those in FPT group when instructed to maintain equal priority among tasks. These results somewhat differ from previous findings as VPT is known to accelerate learning and to produce superior mastery in a number of contexts (Gopher, 2007). All studies that observed larger improvement with VPT than with FPT included at least one continuous task. For example, in Kramer et al. (1995; 1999), participants had to track six continuously changing gauges and to reset each gauge as soon as it reached the critical region. This perpetual monitoring might be more effortful and, therefore, allow for larger improvement in comparison to discrete tasks. The present study involved combinations of discrete tasks only, which might explain why no larger improvement was observed during VPT, though a larger transfer effect was still observed. Bherer et al., (2005) also observed no superiority in training effect using VPT compared to FPT, as was observed in the present study. The contribution of the present study was to extend this finding to transfer conditions, which was not included in previous studies. The fact that both training groups still showed significant improvement on the fifth and last training sessions suggests that results were not affected by a floor effect. Nevertheless, as Schmidt and Bjork (1992) suggested, the conditions leading to the best transfer effects are not necessarily those that lead to the best performance during training. If anything, the fact that VPT leads to the same magnitude of training-specific improvement than FPT, while still leading to larger transfer effects, only gives further support to the hypothesis that VPT can significantly enhance transfer effects. Retrospectively, it would have been interesting to assess both training groups in a situation of shifting priorities before and after training to see whether VPT participants would have improved to a greater extent in that condition. Indeed, while improvements in both groups were comparable under fixed priority instructions, VPT training might have significantly surpassed FPT in a shifting priority situation. Interestingly, in Kramer et al. (1995), five different processing priorities (20–80%, 35–65%, 50–50%, 65–35%, 80–20%) were used. Since, the present studies used discreet and very simple discrimination tasks, participants were simply asked to focus on one of the tasks as in several others studies (Bherer et al., 2005, 2008; Boot et al., 2010; Silsupadol et al., 2009). Nevertheless, variable attentional ratio may be more taxing for attentional control and therefore, more beneficial than simply prioritizing or not.

VPT is believed to be an efficient way to train the ability to successfully shift priorities among two tasks (Cassavaugh & Kramer, 2009), which is consistent with the specificity of VPT transfer effects for multi-tasking condition. Participants in VPT had to maintain more flexibility in their response patterns because of the continuously changing priority instructions. By contrast, participants in FPT always trained with the same instructions and might have developed skills leading to equivalent improvement to that of VPT, but those skills appeared to be more dependent of the context in which they were trained. Looking at the literature on transfer effects following cognitive training, it appears that transfer effects are more frequent in training that tap into executive functioning, namely updating, flexibility, and divided attention (Brehmer, Westerberg, & Backman, 2012; Karbach, Mang, & Kray, 2010; Karbach & Verhaeghen, 2014; Li et al., 2010), possibly because executive functions are less context-dependent and rely on flexible decisions based on the environment.

It would therefore be plausible that VPT leads to larger transfer effects than FPT because it is more taxing on executive and attention control. Another, non-exclusive explanation for VPT leading to greater transfer effects than FPT is because there was more variation of the training context in VPT than in FPT. Indeed, variability within training has been put forth as a factor that can result in larger transfer effects (Ahissar & Hochstein, 2004). The rationale is that if individuals are encouraged to perform similar tasks in different ways, they might be able to extract more general learning from their experiences leading to larger transfer effects (Balwin, 1992; Schmidt & Bjork, 1992). A recent study using a similar design has reported that varying the context of training through the training program leads to small benefits on transfer effects (Lussier, Brouillard, & Bherer, 2015). It is therefore possible that VPT superiority was, at least, partially driven by heterogeneity in training context.

This study is in line with others (Brehmer et al., 2012; Green & Bavelier, 2008; Kueider et al., 2012; Richmond, Morrison, Chein, & Olson, 2011) that aimed at identifying the parameters and characteristics that make a cognitive training effective, potent and relevant. VPT has shown promise in improving performance and learning speed in a context in which individuals are required to share and distribute attentional resources among several tasks in a short time period (Gopher, 2007). The original contribution of the present study is to demonstrate that VPT leads to larger and specific modality transfer effects than FPT in older adults. From a clinical stand-point, transfer is crucial since it supports an improvement from laboratory tasks to everyday life tasks (Geusgens et al., 2007). Recent studies tend to show that divided attention training can be to improve dual-tasking performances in various situations (ex.: dual-task walking) in adults experiencing executive dysfunction post-stroke (Couillet et al., 2010; Poulin et al., 2015), in patients with mild to moderate dementia (Schwenk, Zieschang, Oster, & Hauer, 2010), in patients with Parkinson's disease (Canning, Ada, & Woodhouse, 2008; Yogev-Seligmann, Giladi, Brozgol, & Hausdorff, 2012), and in women with mixed-urinary incontinence (Fraser et al., 2014).

From a more fundamental standpoint, most training protocols do not aim at improving a specific stimulus-response mapping, but rather a cognitive function. Future studies should further explore the impact of variations in learning experience in computerized training tasks on transfer effects.

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