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Dual Task Performance of Working Memory and Postural Control in Major Depressive Disorder

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Objective: Previous studies with patients diagnosed with Major Depressive Disorder (MDD) revealed deficits in working memory and executive functions. In the present study we investigated whether patients with MDD have the ability to allocate cognitive resources in dual task performance of a highly challenging cognitive task (working memory) and a task that is seemingly automatic in nature (postural control). *Method:* Fifteen young (18–35 years old) patients with MDD and 24 healthy age-matched controls performed a working memory task and two postural control tasks (standing on a stable or on a moving platform) both separately (single task) and concurrently (dual task). *Results:* Postural stability under single task conditions was similar in the two groups, and in line with earlier studies, MDD patients recalled fewer working memory items than controls. To equate working memory challenges for patients and controls, task difficulty (number of items presented) in dual task was individually adjusted such that accuracy of working memory performance was similar for the two groups under single task conditions. Patients showed greater postural instability in dual task performance on the stable platform, and more importantly when posture task difficulty increased (moving platform) they showed deficits in both working memory accuracy and postural stability compared with healthy controls. *Conclusions:* We interpret our results as evidence for executive control deficits in MDD patients that affect their task coordination. In multitasking, these deficits affect not only cognitive but also sensorimotor task performance.

Keywords: major depressive disorder, working memory, executive function, postural control, dual task

Major depressive disorder (MDD) is a mental illness that affects patients' quality of life, productivity, and even mortality (Doris, Ebmeier, & Shajahan, 1999). MDD is best known as a disorder of affect; however, it also causes performance decreases in various aspects of cognitive processing including attention (Paelecke-Habermann, Pohl, & Leplow, 2005; Watts & Sharrock, 1985), working memory (Rose & Ebmeier, 2006) and aspects of executive function such as cognitive inhibition (Moritz et al., 2002), decision-making (Murphy et al., 2001), and planning (Beats, Sahakian, & Levy, 1996; Elliott et al., 1996; Porter, Mulder, & Joyce, 2003). Executive function is also critical for multitasking, an essential aspect of many everyday activities. In this study we assess the way MDD affects cognitive resource allocation in multitasking.

The experimental study of multitasking uses the dual task paradigm in which participants perform two tasks separately and then concurrently typically under the instruction to give similar attention to both tasks. The quality of multitasking is assessed by the so-called *dual task costs*, defined as the differences between performance on each task in dual relative to single task conditions (for a review see Pashler & Johnston, 1998). Two general types of accounts for dual task costs have been put forth in the literature. The first type, general resource accounts (Cerella, 1985; Kail & Salthouse, 1994; Salthouse, 1996) emphasizes the role of a general pool of cognitive resources that most tasks draw upon (Kahneman, 1973). Under this account, the same individual differences in resources that constrain single task performance apply to dual task performance. Thus, dual task costs simply reflect a shortage of available cognitive resources. The second type, task coordination accounts (Korteling, 1993; Kramer, Larish, & Strayer, 1995; Kramer, Larish, Weber, & Bardell, 1999) attributes dual task costs to an inability for appropriate resource allocation to the concurrently performed tasks. The difference from general resource accounts is that even if the resources required in order to master multiple tasks are available, they cannot be brought to bear on concurrent demands when necessary. Most related explanations follow the working memory model proposed by Baddeley and Hitch (1974) which assumes a central executive component that allocates cognitive resources according to task demands. So conceived, multitasking is a hallmark of executive control and dual task paradigms have been used in previous studies to assess individual differences in executive function, mainly using working memory tasks (Baddeley, 1996; Baddeley & Logie, 1999; Hegarty, Shah, & Miyake, 2000).

The way in which MDD affects working memory has been recently assessed using behavioral and neuroimaging approaches. On the behavioral side, studies have investigated effects of MDD on the basis of extant models of working memory (Baddeley & Hitch, 1974) and executive function (Miyake et al., 2000) with a specific focus on working memory updating which is one of the three executive functions identified by Miyake et al. (2000) and can be assessed using the n-back task (Dobbs & Rule, 1989). Young adult patients with MDD have shown a specific deficit in working memory updating both using verbal (Harvey et al., 2004) and visuospatial (Rose & Ebmeier, 2006) versions of the n-back task, suggesting that this deficit is more likely to be at the central executive rather than the slave systems. On the neuroimaging side, evidence suggests that the depressed brain is in a state of dynamic dysregulation as a result of a disturbance in interactions between the limbic system, responsible for emotional processing, and frontal cortical areas, responsible for cognition, executive function and motor behavior (Giacobbe, Mayberg, & Lozano, 2009; Mayberg, 2003; Mayberg, 2006). Evidence from studies assessing working memory in patients with MDD (Harvey et al., 2005; Matsuo et al., 2007; Rose, Simonotto, & Ebmeier, 2006) has also been attributed to limbic-cortical dysregulation. A key finding of these studies is that when performing the n-back task at the same level of accuracy (with no group differences), patients with MDD exhibited overactivation of the lateral prefrontal and cingulate areas relative to healthy controls. This overactivation may reflect the clinically observed greater effort exerted by patients with MDD in order to perform tasks highly demanding of cognitive processing resources.

In contrast to the cognitively demanding executive control tasks, sensorimotor tasks like walking or postural control are considered almost automatic. That is because healthy young adults can perform these tasks effortlessly in combination with other activities such as talking or reading. However, studies using the dual task paradigm for combinations of cognitive and sensorimotor tasks (Kerr, Condon, & McDonald, 1985; Maylor, Allison, & Wing, 2001; Maylor & Wing, 1996) suggest that in certain groups performance in these tasks may be less automatic than assumed. Reliable dual task costs in concurrently performed cognitive tasks indicated that walking or maintaining postural stability required cognitive resources in older adults (for a review, see Woollacott & Shumway-Cook, 2002) and children (Schaefer, Krampe, Lindenberger, & Baltes, 2008). As to psychiatric disorders, Rapp, Krampe, and Baltes (2006) found that dual task costs were even higher in patients with early Alzheimer's disease compared with age-matched healthy controls. However, little is known about postural stability and dual task performance in patients with MDD. Studies assessing postural stability in this group have focused on postural abnormalities arising as adverse effects of certain types of antidepressive medication, rather than on postural stability per se (Laghrissi-Thode et al., 1995; Li, Hamdy, Sandborn, Chi, & Dyer, 1996; Mamo et al., 2002). Evidence from these studies suggests that impairments of postural control are limited to patients receiving tricyclic antidepressants (TCAs), while patients receiving Selective Serotonine Reuptake Inhibitors (SSRIs) showed no such effects.

In the present study, we asked whether patients with MDD could appropriately allocate cognitive resources under highly challenging conditions such as concurrent performance of two tasks even when one of the tasks (postural control) is presumed to be auto-

matic in nature. To this end we compared a group of young adults (18–35 years old) diagnosed with MDD with age-matched healthy controls. Participants performed a spatial working memory task while standing on a force platform that was either stable or slowly tilting. Postural stability and working memory performance in these two dual task conditions were compared with each individual's performances in the same tasks when administered under single task conditions. Based on evidence from previous studies (Laghrissi-Thode et al., 1995; Li et al., 1996; Mamo et al., 2002), we expected similar performances between groups in single task posture conditions if the well-known effects of medication on postural stability were ruled out by careful screening. We did, however, predict a major deficit in single task working memory performance for the MDD patients.

Comparisons of dual task costs between groups that already differ at the level of single task performance (like MDD patients and controls in working memory) can be problematic. If a component task presents a much harder challenge to one group, differences in dual task costs arise from rather trivial differences in remaining resources. Likewise, dual task costs can be obscured by an underchallenge to the more apt group (as reflected in ceiling effects in single task situations) leaving them with extra resources to compensate for additional challenges of a concurrent task. To avoid these pitfalls we calibrated the difficulty of the working memory task individually by adjusting the number of items to be remembered in a fixed time period (20s) such that each participant could reach 80% correct recall under single task conditions. We considered this approach the closest approximation of equating single task resource demands across individuals. Our key prediction was that MDD patients show higher dual task costs compared with controls because deficient executive functioning makes their task coordination less efficient.

Method

Participants

Fifteen patients with MDD and 24 age matched controls participated in the study. Detailed sample characteristics are included in Table 1. Patients were recruited from the Anxiety and Depression section, University Hospital Sint-Pieter Leuven, Belgium and were all inpatients. Inclusion criteria were a *Diagnostic and Statistical Manual of Mental Disorders* (4th ed.; DSM–IV; American Psy-

Table 1
Sample Characteristics, Means and SD (In Parentheses)

	Controls	MDD
Age (years)	25.4 (3.68)	26.77 (5.29)
Sex: male/female	9/15	3/12
Mean time since first diagnosis (months)	n/a	4.64 (2.87)
Number of hospitalizations	n/a	2.60 (1.06)
Years of education	17.29 (2.82)	16.93 (4.03)
DS Forward (items)	7.71 (1.99)	7.33 (2.06)
DS Backward (items)	7.88 (1.54)	6.87 (1.77)
DSS items in 2 min	91.83 (11.74)	84.12 (11.71)
BDI score	3.62 (3.58)	29.8 (12.54)*

Note. N/A = Not Applicable; DS = Digit Span; DSS = Digit Symbol Substitution; BDI = Beck Depression Inventory.
* $p < .01$.

chiatric Association, 1994) diagnosis of MDD without psychotic features and age 18 to 35 years. Patients were interviewed with the mood modules of the Dutch version of the Structured Clinical Interview for DSM–IV (SCID; First, Spitzer, Gibbon, & Williams, 1996; Van Groenestijn, Akkerhuys, Kupka, Schneider, & Nolen, 1999). Diagnostic information on comorbidity was obtained from medical records and from the team's clinical psychologist. Exclusion criteria were bipolar disorder, organic brain disease and treatment using electroconvulsive therapy. Participants receiving TCAs were not included in the sample because this class of medication causes postural instability and falls more than any other class of antidepressants (Darowski, Chambers, & Chambers, 2009; Li et al., 1996). It is important to note that even though we did not explicitly select participants on the basis of matching for years of education, basic working memory and processing speed (as measured by the DSS and DS, respectively), the two groups were not different in these measures (see Table 1). Further exclusion criteria for patients and controls included medical conditions (ADHD, orthostatic hypotension, operations restricting mobility or balance, peripheral neuropathy, diabetes, vestibular disorders, dizziness/vertigo) or intake of medication known to affect postural control such as sleeping medication (e.g., benzodiazepines; Tillement et al., 2001). Comorbid diagnoses in the MDD group included anxiety disorders (post traumatic stress disorder $n = 2$, general anxiety disorder $n = 2$, and obsessive–compulsive disorder $n = 3$), eating disorders (anorexia $n = 1$ and bulimia nervosa $n = 1$) and borderline personality disorder ($n = 1$). At first assessment, six patients were not receiving antidepressant medication, three were receiving SNRIs, four were receiving SSRIs, and two were receiving Trazodone. Screening tests included the Dutch version of the Beck Depression Inventory (Beck, Steer, & Brown, 1996; Van der Does, 2002) two subtests from the Wechsler Adult Intelligence Scale (WAIS-III; Wechsler, 1997) Digit Span (DS) forward and backward and Digit Symbol substitution (DSS), evaluating working memory and processing speed, respectively. Prior to testing, participants signed an informed consent form. The study was approved by the Psychology Department's ethics committee and was performed in accordance with the 1964 Declaration of Helsinki. Participants were paid 20 euro for their participation.

Apparatus and Tasks

Postural stability was assessed using the NeuroCom Clinical Research System (NeuroCom International, Inc., Clackamas, OR) comprising two independent (23 cm × 46 cm) Six-Degree-of-Freedom AMTI force plates. Vertical forces applied on this platform were recorded at a sampling frequency of 100 Hz and were used to derive the Center Of Pressure (COP) time series in the Anterior-Posterior (AP) and Medio-Lateral (ML) directions. Participants stood on the platform wearing a safety harness that did not constrain body movements and was only engaged in the case of loss of balance, which never occurred in this experiment. Postural stability was assessed in two platform conditions: stable (involving a fixed support) and moving (involving platform rotations around the pitch axis, frequency: 0.3 Hz, amplitude: 3°). Each trial lasted 24s, and comprised a 4-s stabilization period, after which presentation of the visual stimuli for the working memory task or the control task started on a computer screen built into the system's three-sided surround.

The working memory task was presented on a 12" Macbook G4. Participants were asked to look at the screen displaying 12 black squares organized in a 4 (columns) by 3 (rows) grid. Working memory trials lasted for 20s during which the grid of squares was always present. After the start of the trial the image of an apple appeared in succession inside the squares, with a variable inter-stimulus interval, and a presentation time of 400 ms. The number of stimuli within a trial depended on the level of difficulty set for a given participant (see 2.3 for details). The order of stimulus presentation was pseudorandom assuring that within a trial a stimulus did not appear in the same square twice. Participants were asked to remember the positions and order of appearance of the stimuli, and to report them to the experimenter after the end of the trial, without time restrictions. Working memory accuracy was expressed as a percent correct.

The working memory task and the two posture tasks were performed both separately (single task) and concurrently (dual task). In single task assessment of working memory participants performed the task while seated. In single task assessment of the posture tasks, participants were asked to stand on the force platform while performing a simplified version of the working memory task (which we will refer to as the control task). The control task was similar to the working memory task in terms of visual stimulus presentation, but without a working memory component. Specifically it included the same number of items, as specified for each participant using the adaptive testing procedure, but one or two of the apples (one at a random position and in half of the trials an additional one at the end of the series) were yellow instead of red. Participants were asked to remember the position of the last yellow apple they saw. They reported this position after the end of the trial as in the working memory task. This task was used in order to provide the same visual stimuli, thereby inducing similar eye, and possible head, movements in single and dual task posture performance. Even though this task may have a memory component, the memory load is negligible relative to the working memory task. This task was chosen instead of simply watching the stimuli because it provided a check as to whether participants were actually paying attention to all stimuli. That way, the only difference between single and dual task postural performance was working memory load. In dual task, participants performed the working memory task while standing on the force platform. Stimuli were presented on a monitor located 50 cm in front of them at eye level. In dual task performance participants were instructed to perform as well as possible in both tasks.

Procedure

Data were collected in two sessions each lasting 60–90 min. For participants in the control group both sessions took place in the laboratory and for patients the first session took place in the hospital and the second in the laboratory. In the first session, we obtained participant characteristics and we calibrated the difficulty of the working memory task for each participant by means of an adaptive testing procedure. This procedure started with working memory trials including four items and was performed in blocks of three trials. Trials within a block included the same number of items. This number increased by one item when the average accuracy of the three trials within the block was greater than 80%.

This process continued until the number of items in which the target level of less than 80% accuracy was reached.

In the second session, posture and working memory were assessed in single and dual task contexts. Single task working memory performance was assessed with the number of items determined in Session 1, in the beginning (four trials), the middle (three trials), and the end (three trials) of the session. Posture performance was assessed in single (A) and dual task (B) contexts following an ABBA design, starting with three single task trials per condition (stable, moving) followed by four dual task and finally two single task trials in stable and moving platform conditions. The first single task trial in each condition was considered a practice trial and was excluded from analysis, leaving four single and four dual task trials per platform condition for analysis. Stable platform trials were always performed first thereby allowing participants to familiarize themselves with task performance in the easy (stable) condition before they move to the more difficult (moving) one. The ABBA design was chosen in order to control for effects of practice or fatigue.

Data Analysis

Postural performance was quantified by fitting an ellipse to the COP trajectory using principal component analysis. The lengths of the ellipse axes were equal to two standard deviations of the COP trajectory along each axis, fitting 88% of the COP trajectory within the ellipse (Duarte & Zatsiorsky, 2002; Oliveira, Simpson, & Nadal, 1996), thereby excluding extreme deviations. The area of the fitted ellipse, which was the main measure of postural stability, was calculated using Matlab (Mathworks, Natick, MA). Greater ellipse area reflected an increase in postural instability. After ellipse calculations, a square-root transformation was applied before averaging to reduce effects of single-trial outliers. To take individual differences in single task performance into account, and to allow for comparisons of costs across tasks (posture, working memory) we calculated proportional Dual Task Costs (DTCs). DTCs were expressed as a percentage of single task performance (Doumas, Smolders, & Krampe, 2008). Statistical analyses were performed using PASW Statistics v. 18.0 (SPSS: An IBM Company). Partial eta square (η^2) values are reported as measures of effect size.

Results

In this section, we report statistical analyses contrasting single with dual task performance in patients with MDD and healthy controls, first in working memory and then in postural stability. Finally, we focus on the way each group is affected by dual tasking, using proportional DTCs.

Working Memory Performance

Working memory was evaluated in two ways, first by analyzing the number of memory items necessary to achieve the target level of accuracy (80%, Figure 1A), and second by assessing changes in accuracy as a result of dual task performance (Figure 1B). As predicted, controls performed the task at 80% accuracy with more items, ($M = 8.13$, $SD = 1.32$ items) compared with patients ($M = 6.73$, $SD = 1.1$ items) $t(37) = 3.39$, $p < .01$ (Figure 1A). The individually adjusted accuracy levels were then used to contrast single and dual task performance (Figure 1B). Working memory accuracy in single task performance was not different in the two groups (Figure 1B, white bars), a result suggesting that the individual adjustment to 80% successfully minimized group differences. To contrast single with dual task performance in accuracy (Figure 1B) we conducted a 2×3 mixed-design Analysis of Variance (ANOVA) with group (control, MDD) as between and context (single task, dual task stable, dual task moving) as within-subjects factors, and specified two a priori Helmert contrasts, one between single task (seated) and the mean of the two dual task conditions, and one between the two dual task conditions. Results showed that overall, patients with MDD showed reduced working memory accuracy [group $F(1, 37) = 4.58$, $p < .05$, $\eta^2 = .11$] relative to controls. Furthermore, dual task performance resulted in a decrease in accuracy as shown by the contrast of single with the mean of the two dual task conditions [context $F(1, 37) = 6.1$, $p <$
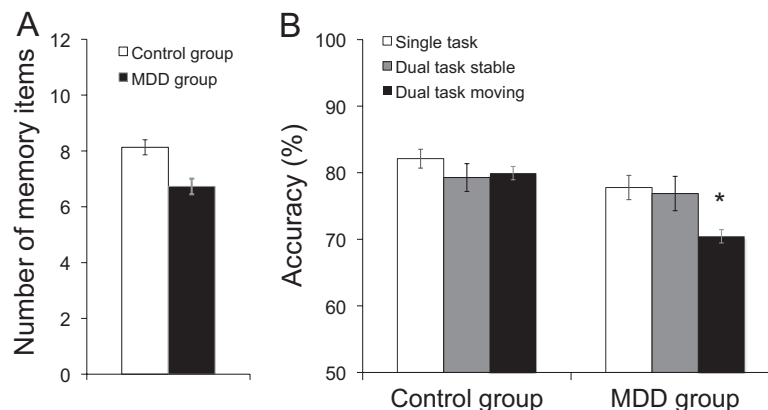

Figure 1. Working memory task performance. (A) Number of items at 80% correct in the two groups. (B) Accuracy in the working memory task while sitting (Single task) and while standing on a stable and a moving platform (Dual task) in the two groups. Error bars reflect ± 1 Standard Error of the Mean (SEM).

.05, $\eta^2 = .14$] whereas the second contrast showed that accuracy was not different between the two dual task conditions. More importantly, a marginally significant interaction at the contrast of the two dual task conditions [*group* $\times$ *context* $F(1, 37) = 4.02$, $p = .052$, $\eta^2 = .1$] suggested that the largest decrease in accuracy during dual task performance was observed in patients with MDD on the moving platform condition (Figure 1B). Post hoc *t* tests confirmed this observation by showing that in dual task performance on the moving platform patients' accuracy was both lower than controls' in this condition $t(37) = 2.55$, $p = .015$, and lower than their own accuracy on the stable platform $t(14) = 2.48$, $p = .026$. In summary, we have shown that patients with MDD exhibit, not only reduced working memory accuracy relative to controls (Figure 1A) but even when this difference is minimized they show dual task performance deficits when posture task difficulty increases on the moving platform (Figure 1B).

Postural Control

Ellipse area results are depicted in Figure 2A for stable and Figure 2B for moving platform conditions. We conducted a 2 × 2 × 2 mixed-design ANOVA with group (control, MDD) as between and context (single task, dual task) and platform (stable, moving) as within-subjects factors for ellipse area. As predicted, performance on the working memory task while standing (dual-task) caused an increase in ellipse area [*context* $\Delta M = 24.27$, $SD = 56.95$, $F(1, 37) = 7.96$, $p < .05$, $\eta^2 = .17$] and this increase was greater in patients with MDD [*group x context* $F(1, 37) = 4.12$, $p < .05$, $\eta^2 = .10$]. Importantly, patients and controls did not differ in terms of postural stability, and the moving platform manipulation was successful in producing a 10-fold increase in ellipse area (see differences between Figures 2A and 2B) relative to the stable condition [*platform* $\Delta M = 340.25$, $SD = 145.05$, $F(1, 39) = 209.11$, $p < .01$, $\eta^2 = .85$] reflecting a sizable increase in instability.

Proportional Dual Task Costs in Posture and Working Memory

After demonstrating group differences for both tasks at the level of performance differences in ellipse area and working memory accuracy (absolute dual task costs), we then assessed proportional dual task costs. The aim of this analysis was to compare costs across modalities (i.e., posture vs. working memory) and to test whether patients with MDD differed from controls in terms of their preferred resource allocation pattern (i.e., whether one group prioritized one modality over the other). Dual task costs are depicted in Figure 3A for working memory and 3B for posture. One-sample *t* tests comparing each value of dual task costs with zero were performed to identify the conditions in which reliable costs were observed. Only the MDD group showed costs that were reliably different from zero. Specifically, in working memory (Figure 3A) patients with MDD showed reliable costs when they performed the working memory task while standing on the moving platform $t(14) = 5.48$, $p < .01$, confirming our finding for reduced accuracy only in this condition (Figure 1B). In postural control (Figure 3B), they showed costs both in the stable $t(14) = 2.18$, $p < .05$ and in the moving platform conditions $t(16) = 2.23$, $p < .05$ in line with our ellipse area results for greater instability in dual task performance in both platform conditions in this group (Figure 2A, B). A 2 × 2 × 2 mixed-design ANOVA with group (control, MDD) as between and task (posture, memory) and platform (stable, moving) as within-subjects factors showed that costs were greater in posture compared with memory [*task* $F(1, 37) = 9.37$, $p < .01$, $\eta^2 = .20$]; however, no other main effects or interactions were shown in this analysis.

Discussion

The aim of the present study was to investigate dual task performance deficits in patients with MDD. To this end we studied concurrent performance of working memory and postural control, a seemingly automatic sensorimotor task vital for everyday functioning. In line with previous studies, results showed that patients with MDD exhibited reduced accuracy in working memory relative to healthy controls (e.g., Rose & Ebmeier, 2006); however, no group differences were observed in postural control. To equate resource demands of the working memory task we individually adjusted task difficulty. This approach was largely successful in providing similar levels of task challenge in the two groups as shown by the absence of single task differences between patients with MDD and controls in working memory accuracy. Our main finding was that patients showed greater postural instability in dual task performance on the stable platform, and more importantly
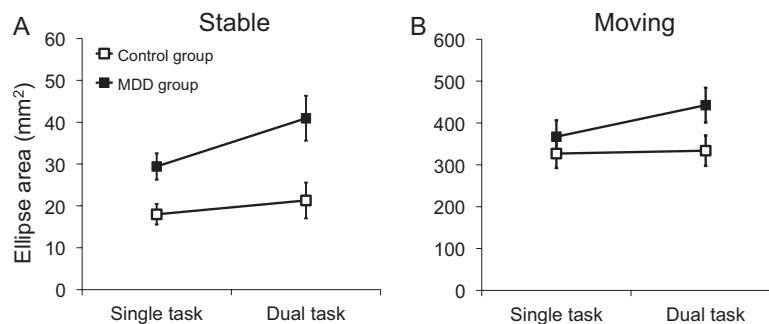

Figure 2. Postural stability assessed on (A) stable and (B) moving platform conditions in single and dual task performance in the two groups. Note that the *y*-axis scale at (B) is 10 times greater than in (A). Error bars reflect ± 1 SEM.
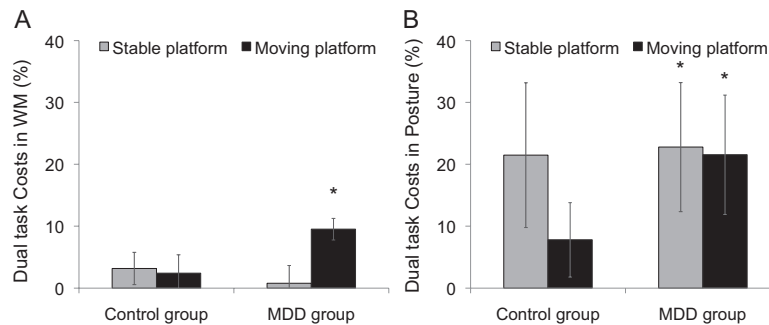
Figure 3. Proportional Dual Task Costs in (A) Posture and (B) working memory. Stars denote values reliably different from zero. Error bars reflect ± 1 SEM.

when posture task difficulty increased (moving platform) they showed deficits in both working memory accuracy and postural stability. We interpret these results as evidence for executive control deficits impairing MDD patients' task coordination abilities, which may be over and above differences in available cognitive resources.

It is instructive to see our main finding in the context of recent evidence for a deficit in working memory updating in patients with MDD, which is present in both verbal and visuospatial memory tasks (Harvey et al., 2004; Rose & Ebmeier, 2006). According to these studies, this pattern of findings implies deficits in the central executive rather than in the slave systems of working memory (Baddeley, 2003; Baddeley & Logie, 1999). Our results are in agreement with this interpretation in the sense that major depression does not only affect the storage aspects (i.e., available resources) of working memory, but strongly impairs executive function. Our findings extend previous work by showing, that in addition to working memory updating, another executive control process affected by MDD is dual tasking or task coordination. We argue that this impaired executive function, responsible for resource allocation in multitasking, produced the observed differences in absolute dual task costs even between two groups who showed no single task differences on either task.

Apart from demonstrating dual task costs in the absence of single task differences, support for the presence of impaired resource allocation in patients with MDD comes from effects of increasing posture task difficulty under single and dual task conditions. In postural control, patients and controls showed similar stability on the stable platform, and the increase in task difficulty (moving platform) did not affect patients' postural stability any more than controls' under single task conditions. Furthermore, working memory accuracy was unaffected by depression in single- and even in dual task performance on the stable platform. However, the increase in posture task difficulty during dual tasking resulted in dual task costs in working memory only in patients. This result suggests that patients with MDD could not accommodate the increased demand for task coordination or resource allocation in dual task performance on the moving platform. One way in which this task coordination deficit could manifest itself in our dual task paradigm could be as follows: In the moving platform condition, when patients' balance is perturbed while performing the working memory task it is very difficult for them to shift cognitive resources from memory to posture quickly in order to

correct their balance. This deficit in task coordination may result in a decrease in their capacity to encode the position of the presented visual stimulus.

Pronounced dual task costs relative to healthy young adults have been observed in children (Schaefer et al., 2008) and older adults (Doumas et al., 2008). These findings have been attributed to an increased need of cognitive resources for sensorimotor functions in old age (Woollacott & Shumway-Cook, 2002) and to the still developing automatization of such functions in children. The need to "invest" cognitive resources into posture arises from differences in single task postural control and from pronounced effects of posture task difficulty. Typically, in dual task performance in these groups, when posture task difficulty increases costs in posture decrease and costs in cognition increase, reflecting a flexible shift in the allocation of the (limited) resources from memory to posture to support stability. This shift is vital especially in older adults in order to prevent an increase in instability leading to fall accidents. Such compensatory mechanisms, together with the reduced cognitive capacity relative to young adults in both groups produce higher dual task costs. In principle we could adopt this explanation for the findings of the present study and assume that posture also requires more cognitive resources in young adults with MDD. However, our MDD participants did not show the described trade-off pattern nor did they differ from controls in single task performance. Still, we cannot fully rule out that differences in general resources between controls and patients continued to contribute to our findings. At a general level, we believe that explanations in terms of general resource models and task coordination are not mutually exclusive.

Our findings also speak to individual and contextual differences with regard to how postural control is achieved, whether it is an automatic task or it requires considerable extra investment of cognitive resources. In our paradigm we consider posture performance "automatic" if the task can be performed without costs for a concurrently performed cognitive task at levels that engage a large part (if not all) of the individual's cognitive capacity (Woollacott & Shumway-Cook, 2002). Thus, the small amount or the absence of dual task costs in healthy young adults in the present and in other studies (Doumas, Rapp, & Krampe, 2009; Doumas et al., 2008; Rapp et al., 2006; Smolders, Doumas, & Krampe, 2010) indeed suggests that these individuals can perform postural control tasks with a minimum or no interference from high-level cognitive processes. As we discussed earlier, this is not the case for children

and older adults for whom considerable dual task costs indicate cognitive resource demand on the part of postural control. This evidence implies that postural control is less automatic in these groups. Note that in this context automaticity refers to a gradual characteristic rather than an all-or-none state. In the present study patients with MDD showed greater absolute dual task costs only in posture when task challenge was low (stable platform), but in both tasks when challenges to stability increased (moving platform). This finding demonstrates that postural control is clearly not automatic for these patients in situations where stability is really challenged, but the same individuals can probably rely on some automatized control processes in conditions with lower postural challenge. Likewise we expect to see cognitive resources complementing automatic processes in healthy young adults if task challenge is sufficiently increased. Determining the degree of automaticity in MDD patients' postural control by systematically varying challenges to stability seems a promising route for future research to elucidate these aspects.

Evidence for the role of deficits in overall resources in patients with MDD also comes from recent neuroimaging studies. When MDD patients and controls performed a working memory task (n-back) at the same level patients exhibited greater activation of the anterior cingulate and the lateral prefrontal cortex, two areas identified as part of a working memory network in this task (Harvey et al., 2005). Similarly, neuroimaging assessments of dual task performance have shown that the rostral anterior cingulate cortex is the brain area that exhibits additional activation in dual task performance, in contrast with successive performance of the same tasks (Dreher & Grafman, 2003). It may be speculative to generalize from these neuroimaging studies to our results, however, it is important to note that the increased activation of the anterior cingulate cortex in patients with MDD, together with its increased involvement in performance of a working memory task in a dual task setting make the "overload" of the anterior cingulate cortex a potential cause of the dual task decrements shown in the present study.

In recruiting our patient sample we had to make several, at times pragmatic, decisions and the resulting limitations in our study need to be acknowledged here. Our patients were a nonhomogeneous group in terms of the medication they received and in terms of comorbid disorders. Specifically, they were receiving different kinds of medication (medication free, SNRI, SSRI, trazodone) and 10 out of 15 of them had a comorbid psychiatric disorder. The reason we allowed for these variations was that our inclusion criteria were already rigorous in terms of medical conditions and medication. For example, we already excluded patients taking sleeping pills that cause drowsiness and dizziness, and we emphasized exclusion criteria that ensured that all remaining participants could perform the postural control tasks. Provided that a large proportion of MDD patients take sleeping pills, this factor introduced great limitations on the available patients. Thus, in the remaining inpatients the wide range of antidepressants received and the multiple comorbid disorders made the selection of a sample with only MDD who would also take the same kind of medication impossible. Nonetheless, we believe that in future studies with larger sample sizes the effects of factors such as medication and comorbid diagnosis could potentially be modeled in the analysis, thereby addressing these limitations.

Another limitation that deserves discussion relates to our adjustment of working memory accuracy to 80% levels. It is important to clarify that this method does by no means directly equate working memory nor effort. We certainly think, however, that our approach has proven useful in the present study in promoting similar levels of baseline memory performance thereby neither under- nor over-challenging participants. To systematically assess individual differences in working memory performance as a function of invested effort individual performance-accuracy functions must be assessed at varying levels of difficulty (e.g., 80%, 60%, and 40%). In healthy young individuals this approach takes extensive testing over multiple sessions (Kliegl, Mayr, & Krampe, 1994), an unrealistic scenario in MDD patients.

In conclusion, the present study shows that patients with MDD show, not only a working memory deficit, but also a clear deficit in dual task coordination of a cognitive and a sensorimotor task. Our findings suggest that the executive function deficits observed in patients with MDD affect their ability to coordinate concurrent performance of two tasks, even when one of these tasks is an over practiced everyday task such as postural control. We believe that our evidence for increased instability in dual task performance even in patients who do not receive medication known to cause severe balance problems may have direct implications for the clinical process and the long-term stabilization of patients after the end of therapy. Health care professionals and patients must be aware that physical condition is not just affecting general health and well-being but has direct consequences for the mechanisms of attention and cognitive resources individuals can dedicate to the therapeutic process in order to reestablish normal, stable living conditions. A specific benefit of this approach is that it could easily be implemented as a complementary measure during acute treatment and develop into the patients' own responsibility during posttreatment periods.

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