Cognitive Performance and Specific Deficits in OCD Symptom Dimensions: IV. Impairments in Manual Movement Control

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Abstract

Objective: The aim was to study cognitive factors of movement control related to everyday actions in obsessive-compulsive disorder (OCD). Simple everyday coordination tasks as well as a new test were developed to study repetitive arm movements. The nature of compulsive behavior in OCD seems to suggest that aspects of movement control are dysfunctional.
Methods: Six OCD patients were compared to 15 healthy controls with sub-clinical obsessive-compulsive tendencies and 14 non-clinical controls. Four movement tasks targeting eye/hand coordination of fine and gross manual motor skills were employed. Standard clinical and psychological background measures were also administered.
Results: The OCD patients were impaired in eye/hand coordination of fine motor skills compared to gross motor skills. Furthermore, the deficiencies varied with the degrees of freedom of movement and symptom severity. The deficiencies showed stereotypical performance patterns.
Conclusion: The findings seem to reflect deficits in attention allocated to the tasks, sub-served by the executive function system. It is argued that the characteristics of compulsive behavior are linked to a lack of attentional resources and consequently, a failure to coordinate movements with multiple degrees of freedom often resulting in stereotypical or compulsive behaviors with a small number of degrees of freedom (German J Psychiatry 2012; 15(1): 32-40).

Keywords: Obsessive–compulsive disorder, symptom dimensions, cognitive motor control, motor stereotypy, cognitive dysfunctions, anxiety

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Introduction

Obsessive-compulsive disorder (OCD) is characterized by a wide range of dysfunctional thoughts and behaviors. The obsessional thoughts often trigger the urge to carry out compulsive behaviors in order to neutralize the obsessional fears and prevent them from happening. Normally compulsions are assumed to be dependent on obsessive thoughts, however it might well be that compulsive behaviors are triggered independent of obsessions (American Psychiatric Association, 2000), in particular when rigid movement patterns are considered. Therefore, the current study focuses on the analysis of compulsive behaviors which may occur independent of obsessive thoughts when performed. Furthermore, the compulsive aspect of OCD is highly characterized by repetition and stems directly from behavioral acts carried out by the individual such as different checking, washing and symmetry rituals. The ability to channel out unimportant visual information in order to fully focus attention on a compulsive ritual is suggested to be dysfunctional (e.g., Hartston & Swerdlow, 1999). This is likely to leave patients with a sense that the motor rituals were not carried out in a 'just right' manner (Leckman et al., 1994; Summerfeldt et al., 2004), triggering the stereotypical behaviors.

The quantification of these repetitive movements in OCD has rarely been systematically investigated. The execution of motor rituals in OCD depends on the role of the sensory input and the cognitive control of movement, which may tap another aspect of the specificity of cognitive deficits that are thought to exist in the disorder (e.g., Kuelz et al., 2004). From a behavioral perspective it has been postulated that the control of motor rituals shows similar patterns in animals and humans (Eilam et al., 2006). The movement range is limited to a few objects and locations with specific movement patterns occurring among these objects and locations. When stereotypical animal behaviors such as searching for food or sniffing to familiarize themselves with the environment were compared to OCD patients and healthy controls performing comparable human behaviors such as locking the car, remarkably similar patterns of motor rituals were found (Eilam et al., 2006). Human rituals were also found to occur in a few specified locations where systematic actions took place and with OCD patients' actions coinciding with those of controls (Eilam et al., 2006). These observations may suggest that motor rituals in animals and humans are controlled by the same cognitive processes and where movement control in OCD is assumed to break down at some point during the evaluating of environmental stimuli. An analysis of specific processes seems therefore necessary in order to understand the nature of cognitive control mechanisms (Henderson & Dittrich, 1993).

Characteristic deviation of neuropsychological functioning in OCD targeting cognitive functions such as decision-making, memory, attention and executive functions as well as emotion processing has been systematically investigated recently (e.g., Dittrich et al., 2010a,b, 2011b,c; Henderson & Dittrich, 1993; Kuelz et al., 2004; Rubies et al., 2001). However, a third important component of intact neuropsychological functioning, namely motor behavior and movement control has not yet been investigated systematically and seems to lack the theoretical focus it deserves in OCD. The control of motion involves the awareness of the position of the body parts in relation to each other while selectively attending to an external goal. Motor control is therefore assumed to be guided by the degree of attention allocated to a task to remain spatially aware of external reference points and targets (Dittrich & Hawken, 1996; Gazzaniga et al., 2002). The role of attention in OCD related to cognitive control of repetitive hand and arm movements has scarcely been investigated in the laboratory setting (Dittrich et al., 2012), but self-paced finger movements have been found to be impaired (Leocani et al., 2001). Moreover, obsessive-compulsive (OC) symptoms have been noted in patients with neurological movement disorders such as Parkinson's disease (Alegret et al., 2001), Huntington's disease (Martin et al., 1993), Sydenham's chorea (Swedo et al., 1989) and Tourette's syndrome (Watkins et al., 2005). Dysfunctional processing in the basal ganglia is thought to be involved in these conditions (Gazzaniga et al., 2002) and this brain structure is also reported to be affected in OCD (e.g., Graybiel & Rauch, 2000; Kwon et al., 2003). Pathological changes in the basal ganglia were also suggested following an investigation of the kinematics of fine motor skills in a group of 22 non-medicated OCD and healthy control participants (Mavrogiorgou et al., 2001). They reported that the OCD patients had impaired handwriting because of a lower peak velocity and it was further revealed that the symptom severity in the OCD patients affected the dysfunctional hand-writing abilities. Therefore, the involvement of the basal ganglia in neurological movement disorders and in studies targeting motor control performance in OCD can give some clues to the location of the brain dysfunction in OCD.

The purpose of this study was to investigate the abilities of OCD patients to perform simple movement coordination tasks such as eye/hand coordination, throwing and handwriting, thus the stereotypy of individual movement units was assessed. In this study, an extension to the purely behavioral approach (Eilam et al., 2006) in studying compulsions in OCD was applied. Specifically, a new test of fine motor skills was also developed to control for ritualistic/stereotypical arm movement behavior. Therefore, motor skills were studied in terms of the X (right and left), Y (near and far) and Z (raising and lowering of hands) directions in space. In this sense, the performance on the different movement tasks is dependent on different body parts which are limited to a certain number of degrees of freedom of movement directions. Hierarchically, the shoulder is the most rigid body part followed by the elbow, wrist and fingers. For example, movement skills that assess the distance to the target (Y direction) and the height of the movement (Z direction) are essential in a ball throwing task and here the shoulder would in the majority of cases represent one degree of freedom and the elbow two, while it is expected that the wrist is fixed in a locked position. Hand-writing (X direction) is dependent on the finger movements when the lower arm is fixed and during such finer movements the degrees of freedom increase to at least four: one for each of the two peripheral finger joints and two for the proximal one. The performance in a group of OCD patients was compared to healthy controls displaying sub-clinical OC tendencies and those not displaying such tendencies, comprising the non-clinical control group. Individuals who are not clinically diagnosed with OCD but still display OC tendencies may also be impaired when performing cognitive tasks (e.g., Mataix-Cols, 2003). It was therefore of interest to investigate whether the presence of OC tendencies would negatively impact on the movement performance in healthy individuals who otherwise reported no history of mental disorders. It was hypothesized that the OCD patients compared to the sub-clinical and non-clinical group would need more time to complete the hand-writing task.

Methods

Participants

There were six OCD patients (5 female, 1 male) meeting criteria for a DSM-IV-TR (American Psychiatric Association, 2000) diagnosis with a mean age of 33.0 years (standard deviation (SD) = 12.4). Three of the patients presented with symmetry/order and perfectionism symptoms, two with contamination fear and one with obsession checking behavior. At the time of testing all patients received stable doses of selective serotonin reuptake inhibitor medication. The healthy participants who volunteered to take part were recruited from the University of Hertfordshire and the general Hertfordshire population by newspaper and posted advertisements. Initially 50 healthy controls were recruited and in order to warrant inclusion in either the sub-clinical or non-clinical group, only participants within the healthy control group scoring above or below the group's mean on both the Yale-Brown Obsessive-Compulsive Scale (Y-BOCS; Goodman et al., 1989) and the Cognitive Assessment Instrument for Obsessions and Compulsions (CAIOC-18, 18-item version; Dittrich et al., 2010a, 2011a) were included. This decision was taken because group inclusion in the sub-clinical domain should be based on a wide range of OC tendencies. In addition, this cut-off point was chosen at the start of the experiment. The healthy control group had a mean score on the Y-BOCS of 4.9 (SD = 3.3) and 28.5 (SD = 12.6) on the CAIOC which meant that 15 healthy individuals were included in the sub-clinical OC group (8 female, 7 male) and 14 healthy individuals were included in the non-clinical control group (12 female, 2 male). Mean age in the sub-clinical OC group was 27.5 years (SD = 13.0) compared to 35.2 years (SD = 17.0) in the non-clinical control group. Consequently, 21 participants were excluded from further analysis.

The study was approved by the Hertfordshire Partnership NHS Trust Local Research Ethics Committee, UK. Data in this manuscript were obtained according to the Helsinki Declaration.

Design

The experimental study used a mixed design, with the between-subjects factor group (OCD/sub-clinical/non-clinical) and the within-subjects factor error for the buzz wire (first half/last half), writing (overline/underline), ball throwing (over-arm/under-arm) and the rollerball (left/right) tasks. In addition, time (over-arm/under-arm) was the within-subjects factor for the ball throwing task.

Materials

The clinical and psychological testing measures and the four neuropsychological tasks administered in the current study are separately described below.

Clinical and psychological testing

Standard background instruments were administered to all participants and included the Mini International Neuropsychiatric Interview (MINI; Sheehan et al., 1998), Y-BOCS, Montgomery-Åsberg Depression Rating Scale (MADRS; Montgomery & Åsberg, 1979), State-Trait Anxiety Inventory (STAI; Spielberger et al., 1983), CAIOC and the National Adult Reading Test (NART; Nelson, 1982). Further details about these tests can be found in Dittrich et al. (2010a). In addition, the Locus of Control (LoC; Rotter, 1966) scale was selected to assess the extent to which individuals believe that they can control life events that affect them.

Neuropsychological tasks

Buzz wire. The task is to move a metal hook around but not touching a metal shaped wire with various curves. The hook is moved from a yellow starting point at one end of an apparatus to the base of the wire at the other end. The participants are given one practice trial before they are assessed on ten trials and whenever the metal hook touches the metal shape a buzzer sounds but the participants are instructed to continue to the end even if they make errors. The examiner starts each trial with the verbal cue 'go' and the trial stops when the participants have moved the hook around the wire shape to the end foot. The key measures were total movement time for the ten trials and total errors during the first half and last half of the task.

Writing. The task is to write the word 'paced' three consecutive times next to each other in three different font sizes (12, 14, 16) defined in Microsoft word. The writing is performed within pre-determined font parameters indicated on an A4 sheet. The participants are instructed not to write over and under the upper and lower line parameters, but write as closely as possible to the given parameters. Participants are also informed that they could write or print. One practice trial for each font is given before three trials in each font are completed during the assessment stage. The key measures were total completion time, overline and underline errors and the number of overlapping words (e.g., an error was counted if the 'd' in 'paced' touched the 'p' in the next consecutive 'paced').

Ball throwing. The task is to throw ten tennis balls into a receptacle 1.5 meters away using both over- and under-arm throws. Three practice throws each for over- and under-arm are given before ten over-arm and ten under-arm throws are performed in the assessment stage. The participants are instructed to perform the throws in one motion from shoulder height (over-arm throw) or hip height (under-arm throw). A ball that did not land inside the receptacle, or bounced off the floor or the wall before landing inside the receptacle, was counted as an error. The key measures were total completion time each for over- and under-arm throws and total errors each for over-arm and under-arm throws.

Rollerball. A new task to test stereotypical behaviors was developed where the participants were instructed to roll, not bounce, a larger (roller) ball down a 1300 millimeters (mm) long X 640mm wide apparatus board to displace a centrally placed target ball and avoid touching any of the two distractor balls placed 105mm apart on each side of the target ball. The apparatus board is presented on a table in front of the participant. The rollerball had to be released anywhere before a red horizontal line (200mm from the start edge) otherwise a target miss was counted. A strike from the front (no rebound displacing the target ball) constituted a correct hit. One practice trial was provided following ten assessment trials. Key measures were total completion time and total target misses to the left and right.

Procedure

On the day of testing during the clinical interview the patients were screened with the MINI to exclude past and

Table 1. Clinical and psychological background characteristics in the OCD, sub-clinical and non-clinical group

	OCD (n = 6)		Sub-clinical (n = 15)		Non-clinical (n = 14)		
Variable	Mean	SD	Mean	SD	Mean	SD	F value
Age (years)	33.0	12.4	27.5	13.0	35.2	17.0	n.s.
Education (years)	2.7	1.4	3.0	0.0	4.1	2.9	n.s.
Verbal IQ	113.8	3.7	110.6	4.6	113.3	7.8	n.s.
Y-BOCS (max 40)	22.5	4.6	5.7	1.4	1.0	1.2	206.4***
MADRS (max 60)	20.0	6.2	9.4	5.1	4.1	3.9	22.7***
STAI-state (max 40)	61.0	10.6	36.6	8.3	26.4	4.8	44.2***
STAI-trait (max 40)	61.0	8.3	45.0	7.9	34.9	5.1	30.0***
CAIOC (max 108)	63.0	8.7	42.5	7.8	16.8	7.2	86.2***
LoC (max 23, external)	12.8	5.7	12.7	4.6	8.5	3.2	4.1*

CAIOC, Cognitive Assessment Instrument of Obsessions and Compulsions; LoC, Locus of Control; MADRS, Montgomery-Åsberg Depression Rating Scale; SD, Standard deviation; STAI, State-Trait Anxiety Inventory; Y-BOCS, Yale-Brown Obsessive Compulsive Scale; df (one-way ANOVA) = 2, 32; ***p < .001; *p < .05

present history of mental problems. During the same session, ratings of OCD severity (Y-BOCS), depression (MADRS), and predicted verbal IQ (NART) were established. The self-rated background questionnaires STAI, CAIOC and LoC were either completed on the day of recruitment or at home and posted back using a pre-paid envelope. The healthy control participants were assessed with the MINI and rated on clinical measures (Y-BOCS, MADRS) and the NART. The self-rated clinical and psychological measures (STAI, CAIOC, LoC) were completed on the day of testing. The neuropsychological tasks were administered in a quiet room in a hospital and at the University of Hertfordshire, UK.

Data analysis

The data were analyzed using the Statistical Package for the Social Sciences version 16.0 (SPSS Inc., 2008). The categorical variables gender and handedness were subject to Pearson chi-square analyses. The data from the clinical and psychological measures were analyzed with one-way analysis of variance (ANOVA). The data from the neuropsychological task performance were submitted to repeated-measures ANOVA and one-way ANOVA. Post-hoc least significant difference tests were performed to follow up main effects. The partial eta squared (η^2_p) was used as an effect size measure, which indicates the proportion of total variability attributable to a factor. A η^2_p of .01 is considered a small effect size, .059 a medium effect size and ≥ .138 a large effect size (Cohen, 1988). In the OCD and sub-clinical OC group, correlations between the Y-BOCS, MADRS, STAI-state, STAI-trait, CAIOC and the neuropsychological task measures were examined using Pearson product-moment correlation. State and trait anxiety were controlled for during statistical testing because analysis revealed significant correlations of STAI-state and STAI-trait with the movement task characteristics in the OCD group. Error bars in the figures represent the standard error of the mean.

Results

Scores on state and trait anxiety were used as covariates when one-way ANCOVAs were conducted to examine the performance on the movement tasks in the OCD, sub-clinical and non-clinical group. Only results that deviated from the standard results are described.

The results of the background measures are described first followed by the neuropsychological movement performance in the three groups.

Demographic, clinical, and psychological background measures

The OCD, sub-clinical and non-clinical group did not differ significantly in age, education, and predicted verbal IQ (Table 1). One-way ANOVAs revealed significant differences in scores on the Y-BOCS, $F(2, 32) = 206.434$, $p < .001$, MADRS, $F(2, 32) = 22.773$, $p < .001$, STAI-state, $F(2, 32) = 44.205$, $p < .001$, STAI-trait, $F(2, 32) = 29.988$, $p < .001$, CAIOC, $F(2, 32) = 86.157$, $p < .001$ and LoC, $F(2, 32) = 4.088$, $p = .026$. Post hoc tests revealed for all measures except the LoC that the OCD patients scored significantly higher than both the sub-clinical and non-clinical group ($p < .001$ for all) and that the sub-clinical group scored significantly higher than the non-clinical group ($p < .01$ for all). On the LoC, post hoc tests revealed that the external score in the non-clinical group was significantly lower compared to the OCD ($p = .013$) and the sub-clinical group ($p = .048$).

Simple movement coordination performance

The means and standard deviations for the movement control variables are displayed in Table 2.

Table 2. Means and standard deviations in the OCD, sub-clinical and non-clinical group for the simple movement coordination task measures

	OCD (n = 6)		Sub-clinical (n = 15)		Non-clinical (n = 14)			
Variable	Mean	SD	Mean	SD	Mean	SD	F-value	η^2_p
Buzz wire								
Total time (seconds)	339.5	111.0	193.4	60.4	219.0	101.0	6.121***	.277
Errors first half	19.5	11.9	14.9	11.1	14.3	10.7	<1	.029
Errors last half	38.3	16.0	29.7	14.5	24.6	6.0	<1	.146
Writing								
Total time (seconds)	110.9	21.2	67.0	26.1	88.0	43.6	3.886*	.195
Errors overline	12.8	9.0	6.6	7.6	4.0	4.0	3.687*	.187
Errors underline	9.3	5.8	23.3	14.8	17.7	13.8	2.426	.132
Errors overlapping	1.8	2.2	0.9	1.8	0.2	0.8	2.412	.131
Ball throwing								
Total time over-arm (seconds)	26.6	8.9	23.1	7.3	22.6	5.3	<1	.045
Total time under-arm (seconds)	28.5	7.0	23.0	6.6	22.8	3.6	2.497	.135
Errors over-arm	2.8	2.2	2.7	2.0	3.4	2.0	<1	.026
Errors under-arm	2.7	1.6	2.5	1.8	2.9	2.2	<1	.006
Rollerball								
Total time (seconds)	28.1	6.7	21.5	9.9	22.1	10.3	<1	.063
Total errors left	5.2	1.6	3.2	2.3	3.6	1.7	2.167	.119
Total errors right	3.3	1.4	4.4	1.8	4.0	1.3	<1	.062

df (one-way ANOVA) = 2, 32; ***p < .001; *p < .05

For the buzz wire task, a one-way ANOVA indicated a significant difference for completion time, F (2, 32) = 6.121, p = .006. Post hoc tests revealed that the OCD patients needed significantly longer time to complete the task compared to the sub-clinical (p = .002) and the non-clinical group (p = .008). A two-way repeated measures ANOVA was conducted to compare the number of errors committed during the first and last half of the task. Results revealed a main effect for errors, F (1, 32) = 64.390, p < .001, η^2_p = .668 indicating that participants made more errors in the last half of the task compared to the first.

For the writing task, a one-way ANOVA indicated a significant difference in completion time, F (2, 32) = 3.886, p = .031 and post hoc tests revealed that the OCD patients needed a significantly longer time to complete the task compared to the sub-clinical group (p = .011). Further, a two-way repeated measures ANOVA was conducted to compare the number of overline and underline errors. Results revealed a main effect for error, F (1, 32) = 9.653, p = .004, η^2_p = .232 and a group and error interaction, F (2, 32) = 3.684, p = .036, η^2_p = .187. To examine the interaction, one-way ANOVAs were conducted. The result for overline errors was significant, F (2, 32) = 3.687, p = .036 and post hoc tests revealed that the OCD patients made more errors compared to the non-clinical individuals (p = .011) and marginally more than the sub-clinical participants (p = .062). The result for underline errors was not significant, F (2, 32) = 2.426, p = .104, but further analysis with post hoc tests revealed that the sub-clinical group performed worse than the OCD patients (p = .037). The one-way ANOVA for errors in overlapping words was not significant, F (2, 32) = 2.412, p = .106, but further analysis with post hoc tests revealed that the OCD patients had significantly more overlapping words compared to the non-clinical group (p = .039).

A one-way ANOVA indicated that the total time required to complete the under-arm throws on the ball throwing task was not significant, F (2, 32) = 2.497, p = .098, but subsequent post hoc tests revealed that the OCD patients needed significantly longer time compared to the sub-clinical (p = .050) and non-clinical group (p = .044).

The performance on the rollerball task was not significant, F (2, 32) = 2.167, p = .131, but subsequent post hoc tests revealed that the OCD patients made significantly more misses to the left of the target compared to the sub-clinical individuals (p = .047; Figure 1).

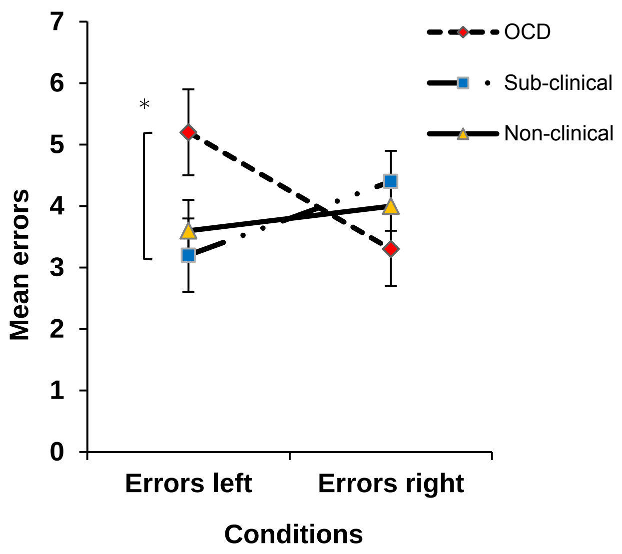

Figure 1. Mean number of errors committed in the OCD, sub-clinical and non-clinical group to the left and right of the target on the rollerball task; *p < .05

Correlation analysis

In the OCD group, correlations were performed to examine the relationship between the movement task measures. For the buzz wire task, a significant positive correlation was found between completion time and errors during the first half of the task, r (6) = .86, p = .029. In addition, errors to the left of the target on the rollerball task corresponded with underline errors in the writing task, r (6) = .66; p = .10. In the sub-clinical group, significant positive correlations were found between underline errors on the writing task and total completion time for over-arm, r (15) = .61, p = .016 and under-arm ball throws, r (15) = .78, p = .001.

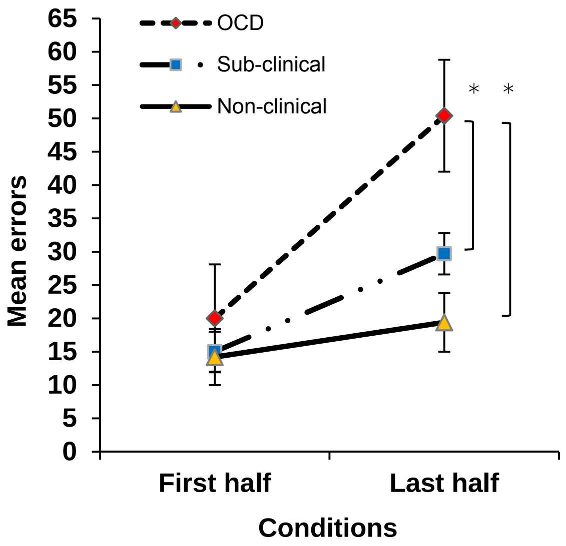

Figure 2. Mean number of errors committed in the OCD, sub-clinical and non-clinical group during the first half and last half of the buzz wire task; *p < .05

Covariate analysis

The correlation analysis between the clinical variables and the movement measures in the OCD group is displayed in Table 3.

When the covariates STAI-state and STAI-trait were included in the analysis only one significant group difference was identified in contrast to standard results (see Table 2 and Figure 2). The difference was found on the buzz wire task where a one-way ANCOVA was conducted and the result for the number of errors committed during the last half of the task was significant, $F (2, 30) = 3.671$, MSE = 141.707, p = .037, $\eta^2_p = .197$. Post hoc tests revealed that the OCD patients (adjusted M = 50.4, standard error (SE) = 8.4) made significantly more errors compared to the sub-clinical (adjusted M = 29.7, SE = 3.1; p = .027) and non-clinical group (adjusted M = 19.4, SE = 4.4; p = .011).

Discussion

The major goal of the present study was to study the compulsive nature of repetitive arm movements in OCD administering four tasks that targeted cognitive control of motor skills. Results revealed impairments in the OCD patients compared to the sub-clinical and non-clinical group for errors during the last half of the buzz wire task when symptoms of anxiety were controlled for. The prediction that the OCD patients compared to the sub-clinical and non-clinical participants would need more time to complete the handwriting task was rejected. It was also found among healthy individuals that there exist high and low scorers on clinical measures, whilst the movement performance did not differ between the sub-clinical and the non-clinical group. The results of the standard analysis revealed that the OCD pa-

Table 3. Correlations in the OCD group between the clinical variables and the movement measures

Variable	Y-BOCS	MADRS	STAI-state	STAI-trait	CAIOC
Buzz wire					
Total time (seconds)	-.03	.27	.70	.78	.55
Errors first half	.44	.05	.70	.72	.38
Errors last half	.44	.24	.40	.75	.58
Writing					
Total time (seconds)	.35	-.36	.09	.40	.13
Errors overline	.65	-.19	.23	.32	-.10
Errors underline	.36	-.40	-.57	-.82*	-.83*
Errors overlapping	.90*	.16	.39	.03	-.15
Ball throwing					
Total time over-arm (seconds)	.45	.04	.47	.12	-.19
Total time under-arm (seconds)	.26	.24	.58	.23	.00
Errors over-arm	.37	-.76	.02	-.29	-.54
Errors under-arm	-.11	-.26	-.58	-.89*	-.68
Rollerball					
Total time (seconds)	.48	.40	.91*	.67	.44
Total errors left	.29	-.75	-.52	-.75	-.87*
Total errors right	-.03	.71	.04	.30	.29

CAIOC, Cognitive Assessment Instrument of Obsessions and Compulsions; MADRS, Montgomery-Åsberg Depression Rating Scale; STAI, State-Trait Anxiety Inventory; Y-BOCS, Yale-Brown Obsessive Compulsive Scale; *p < .05

tients were slower in completing the buzz wire, writing and ball throwing tasks. The patients made also more errors on the writing and rollerball tasks. Taking into account that comorbid symptoms of anxiety are frequent in OCD (e.g., Cohen et al., 2003; Rasmussen & Eisen, 1990) the covariate analysis revealed stable deficits on the buzz wire task. Therefore it is tentatively proposed that the performance in the OCD group involving fine motor skills in everyday actions seems to indicate dysfunctional aspects of the cognitive control of movement.

The four tasks employed in the present study were designed to tap different aspects of movement control. The performance on the buzz wire task puts great demands on eye/hand coordination, accurate fine detailed movements and sustained attention; the writing task assessed the ability to accurately stay within determined boundaries and the ball throwing and the rollerball tasks measured the accuracy of eye/hand coordination. Each task required specific movement patterns and enabled a standardized and detailed assessment of movement control parameters. Taking together, the stereotypical and repetitive compulsive behaviors in OCD can be assumed to reflect a breakdown in the appraisal of sensory stimuli, because of deficits in attentional processes mediated by impairments in executive functions, which are supposed to guide optimal cognitive movement control (see Corben et al., 2001). Similarly to Eilam et al. (2006) who quantified repetitive movements in OCD using ecologically relevant tasks that were symptom specific (e.g., locking a car), it has been demonstrated here that movement control can also be studied in a controlled setting in order to elucidate the nature of cognitive deficits in OCD. Therefore, the cognitive control of movements and the nature of motor rituals can therefore be quantified according to the principles provided by Eilam et al. (2006).

The error pattern in the patient group on the rollerball task seems to reflect deficits in motor control driven by non-conscious behavior because stereotypy in movement control was evident as most of the errors were committed to the left of the target ball. The impaired performance on the buzz wire task, which was a three-dimensional version of the two-dimensional aspect of the writing task, reflects the rigid and restricted movement control in the patient group. This finding confirms previous results of cognitive inflexibility in OCD (e.g., Basso et al., 2001; Dittrich et al., 2010b; Penadés et al., 2005) thought to be sub-served by the executive functions (Greisberg & McKay, 2003). Although the present writing task was different to the tasks applied in Mavrogiorgou et al. (2001) who reported slower peak velocity of writing a sentence and a signature, and in Mergl et al. (2004) demonstrating slowness in hand-motor executions, it shows that different aspects of writing movements in OCD and sub-clinical individuals appear to be impaired (Mavrogiorgou et al., 2001), but when controlling for anxiety in the present study seem to show no differences between the groups. Cognitive control mechanisms that trigger motor programs and attentional processing are thought to be affected in stroke and Parkinson's disease patients (Bekkering et al., 2001; Corben et al., 2001) and similar processing deficits may also be present in OCD patients (e.g., Leocani et al., 2001).

The present motor control paradigm employed can be seen as another way of testing the specificity of cognitive deficits in OCD. Taken together, the results indicated that the OCD patients were impaired in fine movement control following the error rates on the writing and rollerball tasks where the elbow and the wrist are the anchor points allowing movements with high degrees of freedom. This is in contrast to the intact gross movement control performance on the buzz wire and the ball throwing tasks where whole movements are mainly controlled by the shoulder and larger body parts. The finding that the performance deficiencies on two quite different fine motor skill tasks, such as writing and goal-oriented rollerball movement, correlated seems to support the argument that the coordination of the elbow/wrist motor system with multiple degrees of freedom was impaired. Another indication that the OCD patients had a more rigid fine motor control performance follows the inspection of the error variances on the rollerball task that were consistently smaller on all task variables compared to the sub-clinical group and on two out of three task variables compared to the non-clinical group. This observation further supports the notion that the performance in the patient group was more rigid and hence more stereotypical. Furthermore, the results from our group's previous studies (Dittrich et al., 2011b,c, 2012) also revealed that, whenever goal-directed pointing movement are required in motor tasks, OCD patients are impaired in terms of accuracy and/or time, depending on the task characteristics in contrast to movements with a low number of degrees of freedom, e.g. simple key presses (e.g., Dittrich et al., 2010b; Martin et al., 1993).

The current kinematic investigation in OCD may imply that neurological soft motor signs are present in OCD (e.g., Hollander et al., 2005) which could resemble similar motor problems displayed by patients with Parkinson's disease who also show cognitive deficits (e.g., Bekkering et al., 2001; Hodgson et al., 1999). Although the link between neurological soft signs and OCD seems an interesting avenue to explore, caution should be taken as others have not found any evidence for such a relationship when investigating eye movements (Nickoloff et al., 1991). However, here it is argued that the present results are different from Nickoloff et al.'s (1991) and could be explained due to the nature of motor behavior where the oculomotor and the manual motor systems seem to be controlled by different cognitive mechanisms (Bekkering et al., 2001). Therefore, neurological soft signs may only result from deficits in functionally independent motor systems that may not operate optimally.

It is suggested that the buzz wire task was the most demanding movement task due to the length of time needed to complete the task. The fact that the patient group was impaired for errors in the last half and not the first half of the task suggest that dysfunctional motor control was caused by deficits in movement-related attentional processing, leading to a breakdown in eye and hand coordination during cognitively demanding actions. This may be analogous to checking and washing behavior, which are repetitive and time consuming actions, and when the attention that is allocated to the compulsive behavior breaks down this could create feelings of doubt and uncertainty. This will further leave the patients in a constant high state alert, which mediates the urges to carry out repetitive compulsive behaviors. Therefore, intolerance of uncertainty and 'not just right' experiences (e.g., Coles et al., 2005; Tolin et al., 2003) may be directly related to deficits in attentional processing. For the OCD patients a correlation analysis revealed that the longer completion time negatively affected the number of errors during the first half of the buzz wire task and suggests that the patients may have adjusted their speed in the second half of the task, but were nonetheless impaired owing to the assumed deficits in attentional processes. The stereotypical and repetitive behavior in OCD has been shown to be closely linked to cognitive motor control and executive functions. The rituals in OCD consist of highly stereotypical movements and these motor actions may stem from deficits in information processing mechanisms that have wider implications affecting both cognitive and emotional operations that seem to mediate the compulsive behavior.

Prospective studies are encouraged to recruit a larger patient sample and use similar movement tasks following the promising findings reported here in order to further our understanding of the mechanisms mediating cognitive control of repetitive and compulsive movements in OCD. Also, it would be interesting to investigate the nature and the type of errors in OCD and for such analyses video recordings of the performances seem necessary or using an automated motion tracking system. Finally, the challenge for future studies would be to further investigate motor control involving high and low attentional demands in different OC symptom dimensions as well as in patients suffering from compulsions only to delineate the transition or interactions of obsessional thoughts to stereotypical movements and finally ritualistic actions.

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