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Attenuation of access to internal states in high obsessive-compulsive individuals might increase susceptibility to false feedback: Evidence from a visuo-motor hand-reaching task

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ABSTRACT

Background and objectives: The Seeking Proxies for Internal States (SPIS) model of obsessive-compulsive disorder (OCD) posits that obsessive-compulsive (OC) individuals have attenuated access to their internal states. Hence, they seek and rely on proxies, or discernible substitutes for these internal states. In previous studies, participants with high OC tendencies and OCD patients, compared to controls, showed increased reliance on external proxies and were more influenced by false feedback when judging their internal states. This study is the first to examine the effects of false feedback on performance of hand movements in participants with high and low OC tendencies.

Method: Thirty-four participants with high OC tendencies and 34 participants with low OC tendencies were asked to perform accurate hand reaches without visual feedback in two separate sessions of a computerized hand-reaching task: once after valid feedback training of their hand location and once with false-rotated feedback. We assessed the accuracy and directional adaptation of participants' reaches.

Results: As predicted, high OC participants evidenced a larger decrease in their hand positioning accuracy after training with false feedback compared to low OC participants.

Limitations: The generalization of our findings to OCD requires replication with a clinical sample.

Conclusions: These results suggest that in addition to self-perceptions, motor performance of OC individuals is prone to be overly influenced by false feedback, possibly due to attenuated access to proprioceptive cues. These findings may be particularly relevant to understanding the distorted sense of agency in OCD.

1. Introduction

A recent comprehensive model of obsessive-compulsive disorder (OCD) postulates that a core feature of the disorder is impaired access to internal states, including emotions and preferences as well as bodily states and sensations. According to the Seeking Proxies for Internal States model (SPIS; Lazarov, Dar, Oded, & Liberman, 2010; Liberman & Dar, 2009), obsessive-compulsive (OC) individuals seek and resort to *proxies* to compensate for the attenuated access to their internal states. Proxies are substitutes for the internal state that the individual perceives as easier to monitor and discern, such as rules, behaviors, or environmental stimuli (Lazarov, Liberman, Hermesh, & Dar, 2014; Liberman & Dar, 2009). According to the SPIS model, the attenuation of access to internal states in OCD can account for the complex phenomenology of the disorder, including prevailing doubts, repetitive checking, behavior governed by rules and rituals, and a distortion in the sense of agency.

Previous studies have supported the SPIS model by showing that individuals with high OC tendencies have reduced access to various internal states, including relaxation level (Lazarov et al., 2010), muscle tension (Lazarov, Dar, Liberman, & Oded, 2012a,b, Zhang et al., 2017 and Lazarov et al., 2014 in OCD patients), time perception (Gilaie-Dotan, Ashkenazi, & Dar, 2016), sense of understanding (Dar et al., submitted), movement initiation (Ezrati, Sherman, & Dar, 2018) and emotions (Dar, Lazarov, & Liberman, 2016). In various tasks involving these internal states, high OC participants and OCD patients appeared to have attenuated access to these states, were more inclined to seek and depend on external proxies for them, and were more vulnerable to

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the effects of false feedback. For example, using a muscle tensing task, Lazarov et al. (2014) demonstrated that OCD patients had larger errors when asked to reproduce specific degrees of muscle tension, as compared with non-clinical and anxiety control participants. This difference was eliminated when participants were provided with biofeedback as an external proxy for this internal state. In another study (Lazarov, Dar, Liberman, & Oded, 2012b), high and low OC participants were instructed to relax their forearm muscles while viewing false preprogrammed "feedback" on their muscle tension. Each participant underwent two successive phases of putative feedback, one indicating a gradual increase in muscle tension and one indicating a gradual decrease in muscle tension. Following each phase, participants rated their perceived level of muscle tension. As predicted, the ratings of the high OC participants indicated that they relied more on the (false) biofeedback proxy in judging their own level of muscle tension.

Though not originally described as such, the aforementioned studies involving muscle tension suggest that OCD tendencies may be related to deficient proprioception. Proprioception, derived from the Latin word *proprius* meaning "one's own," is defined as information derived from skin and musculoskeletal receptors especially on body movement, body position, muscle tension, balance and sense of effort (Proske & Gandevia, 2012). Proprioception is also considered to be a precursor of the sense of agency (SoA), which is "the registration that I am the initiator of my actions" (Synofzik, Vosgerau, & Voss, 2013). Agency experiences rely on integration and compatibility of predictive and postdictive cues (e.g., Gentsch & Synofzik, 2014; Synofzik et al., 2013; Synofzik, Vosgerau, & Lindner, 2009). In the case of movement, predictive cues include the internal copy of the motor command (Synofzik et al., 2013, 2009; Tsakiris, Prabhu, & Haggard, 2006). Postdictive cues may include external cues (e.g., seeing one's hand moving) and internal cues of proprioception (e.g., feeling the position and movement from skin, muscle and joint receptors). Successful integration of these cues and an intention-sensory outcome compatibility is believed to lead to the SoA (Gentsch & Synofzik, 2014).

Convergent experimental data from a variety of paradigms suggest a reduced SoA in OC individuals (Belayachi & Van der Linden, 2010; Gentsch, Endrass, & Kathmann, 2012; Oren, Eitam, & Dar, 2017, 2016; Rossi et al., 2005). More pertinent to the current study, recent findings comparing active vs. passive acquisition in a head repositioning task suggest that high OC individuals have deficient access to internal cues involved in active movement (Ezrati et al., 2018). Attenuated access to proprioceptive signals may be one of the factors that account for this finding, and in general for the reduced SoA of people with OC tendencies and OCD.

Tasks requiring accurate hand movements are particularly promising for enriching our knowledge on proprioception in OCD. This is because the performance of accurate hand movements demands integration of different types of cues, from an efferent copy of the intention to act, through internal proprioceptive information from receptors in the muscles, joints and skin, to external feedback from exteroceptors, such as the eyes (Proske & Gandevia, 2012).

Studies using false feedback on muscle tension indicate that OC individuals are prone to form their assessments of their own muscle tension in accord with the false feedback they have received (Lazarov et al., 2012a; 2012b, 2014). However, these findings are not informative regarding any potential functional impact of the false feedback; specifically, would high OC individuals be more affected by false feedback not just in their assessment of internal states but on subsequent performance that relies on accurate assessment of these internal states? Accordingly, the current study had two aims. First, to extend the predictions of the SPIS model to the domain of proprioception; and second, to evaluate the impact of false feedback on subsequent performance in individuals with high OC tendencies.

We used a point-to-point hand-positioning task (similar to the task used in Inzelberg, Flash, Schechtman, & Korczyn, 1995 and Jones, Cressman & Henriques, 2009). Participants performed the movements on two separate occasions, each with a different feedback condition. In the valid feedback session, they received visual feedback that was aligned with their hand location, whereas in the false feedback session they received rotated visual feedback. When participants train with visual feedback on their hand location that mismatches their proprioceptive sensation, they tend to rely more on the visual feedback than on the proprioceptive information, at least when the extent of the mismatch is relatively small (Jones, Cressman & Henriques, 2009). Under such conditions, subjects correct their movements based on visual feedback, such that a new mapping between visual input and motor output is learned (i.e. visuomotor adaptation; Krakauer, Ghilardi, & Ghez, 1999; Cressman & Henriques, 2009). Following the previous training, when participants perform reaches without visual feedback, they continue, for a certain period, to produce movements in the direction opposite to the visual rotation. These movements are referred to as "reach after-effects" and result in errors in the direction of movement and final position of the hand (Martin et al., 1996; Krakauer et al., 1999; Krakauer, Pine, Ghilardi, & Ghez, 2000; Baraduc & Wolpert, 2002).

Following the SPIS model, we predicted that compared to individuals with low OC tendencies, individuals with high OC tendencies will rely more on visual feedback as an external proxy and less on internal proprioceptive information when performing point-to-point movements. Therefore, their performance in the "after-effects" blocks should be more affected by the absence of external visual information. Following the same line of thought, we expected that supplying false feedback training will have a larger effect on the performance of high OC participants, as compared to low OC participants.

2. Method and materials

2.1. Participants

Seventy-three Hebrew-speaking right-handed participants were recruited for the study: 38 high OC participants and 35 low OC participants. The participants were students who had completed the Obsessive–Compulsive Inventory-Revised (see Materials below) prior to the experiment and scored in the top and bottom 25% of the distribution of responders, respectively. Five participants were excluded from the study because when they completed the OCI-R again, as part of the experiment itself, their answers no longer placed them in the top or bottom 25% of the distribution. The remaining sample of 68 participants consisted of 34 low OC participants (53% women, mean age of 23.6, $SD = 2.43$, range: 18–28) and 34 high OC participants (79% women, mean age of 23.2, $SD = 2.01$, range: 21–31). The final mean OCI-R score of the low OC participants was 7.17 ($SD = 3.60$ range 2–14) and the corresponding mean for the high OC participants was 38.82 ($SD = 8.6$, range 26–62). All participants reported having normal hearing and normal or corrected vision.

All participants signed an informed consent form prior to participation, received payment or course credit for their participation and were fully debriefed after the completion of the experiment. The experimental protocol was approved by the Tel Aviv University Institutional Review Board.

2.2. Materials and procedure

Self-report questionnaires: The Obsessive–Compulsive Inventory-Revised (OCI-R, Foa, Kozak, Salkovskis, Coles, & Amir, 1998); The OCI-R lists 18 characteristic symptoms of OCD. Each symptom is followed by a 5-point Likert scale ranging from 0 ("Not at all") to 4 ("Extremely"), on which participants indicate the symptom's prevalence during the last month. The OCI-R has been shown to have good validity, test–retest reliability, and internal consistency in both clinical (Foa et al., 2002) and non-clinical samples (Hajack, Huppert, Simons, & Foa, 2004). The participants completed the OCI-R in the screening phase and

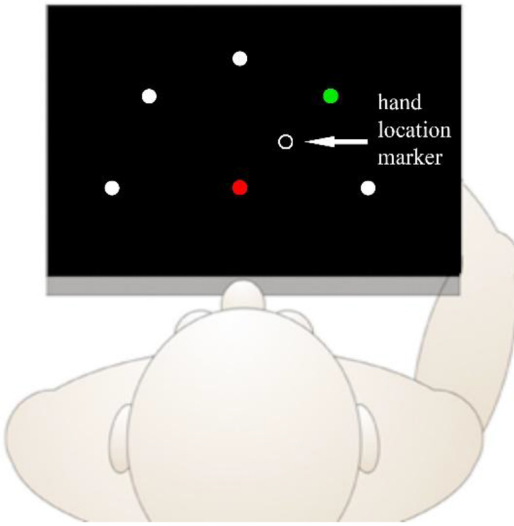

Fig. 1. General display setup.

again in the last part of the experiment itself.

General experimental setup: The experimental apparatus consisted of a digitizer tablet (Wacom Intuos 4, 297 mm*420 mm) placed on a table and connected to a computer (Intel core I7-based Lenovo PC) allowing accurate localization of the stylus position at a rate of 100 Hz. The computer screen (24-inch Dell U2414MB) was placed horizontally 25 cm directly above the digitizer tablet. All experiments were run using the "Repeated Measures" software (Friedman 2014), MATLAB (Mathworks Inc.) that runs on top of the Psychophysics Toolbox (Brainard 1997). Participants were seated at a table in a chair, which was positioned so that they could comfortably see and reach all target positions. Participants held the tablet stylus in their hand. The room lights were dimmed and the participants' view of their right hand was blocked by the computer screen and a black cloth draped between the experimental setup and the participants' right shoulders.

Procedure: The experiment was conducted in two sessions on separate days. The general display setup was similar in all experimental blocks. The computer screen displayed five reach targets represented by 1.5-cm diameter white disks in a 10-cm radius half-circle, with another disk indicating the center of the circle (See Fig. 1).

Each session consisted of 100 reach training trials and 15 reach after-effects trials. In the first session, participants performed the training while seeing a cursor that was aligned with their hand (the valid feedback condition). In the second session, participants performed the training while viewing a cursor that was misaligned from the actual location of their unseen hand (the false feedback condition). To ensure that subjects were unaware of the visuomotor rotation, the cursor rotation increased incrementally across the training trials. This was done by shifting the cursor position 0.26° to the right every trial, i.e. up to 26° to the right in the final trial from the actual hand path (Fig. 2: see Jones, Cressman & Henriques, 2009; Salomonczyk, Cressman, & Henriques, 2011 for similar procedures).

Reach training blocks (valid and false feedback): Participants were asked to move the stylus as quickly and accurately as possible from the central point to one of the target points on the perimeter. The position of the unseen hand was represented on the screen by a cursor (4 mm diameter white disc). Each block consisted of 100 aiming movements, 20 reaches to each of the five reach targets in a pseudorandom order. Trials started when the participant positioned the hand grasping the stylus under the disc representing the central point on the screen. The center disc changed its color from white to red and one of the discs on the perimeter changed instantly to green, indicating that it was the target destination of the current reach trial. The reach was considered complete when the stylus was at the target position or after 6 s.

Reach after-effects trials: After completing the reach training block, participants immediately completed 15 aiming movements, three reaches to each of the five targets in a pseudorandom order, without the cursor. These reach after-effects trials measured errors in participants' reaches and adaptation of their reaches in response to the visual perturbation (i.e., visuomotor adaptation). On these trials, the cursor representing the participant's hand was available only until the participant positioned the stylus at the starting point and disappeared when the participant started to reach towards the target. Participants were instructed to aim for the target disc and hold their end position. Once this end position had been maintained for 500 ms, this was taken to signify that they have reached the target. The visual target disappeared and the trial was considered complete.

Data analysis: Reaching errors were calculated for each trial by two parameters: (1) final position error – absolute distance of the final position of the hand from the target (in cm) and (2) direction error – that was calculated as the angular difference between the initial heading angle, defined as the movement vector from the initial point to a location one third of the reaching path (computed using the arc length), to a straight line from the initial position to the target. We used one third of the reaching path in order to capture the participant's initial intention in the trial, before they correct using visual feedback. Positive angles indicate a counterclockwise (CCW) deviation from the target and negative angles indicate a clockwise (CW) deviation from the target (Fig. 3). We also tracked the rate of movement adaptation during the training trials by computing the initial heading angle, as explained above.

3. Results

As expected, participants adapted their reaching path across training trials in accordance with the false feedback (rotated cursor). Specifically, their initial direction of movement was significantly shifted CCW after training with false feedback. The average initial heading angle of the last 30 trials of the false feedback training block ($M = 19.84°$, $SD = 3.25°$) was significantly shifted CCW compared to the average of the last 30 trials of the valid feedback training block ($M = 2.97°$, $SD = 2.19°$), $F(1, 66) = 1441.42$, $p < .001$, η_p^2=. 0.956. However, there was no main effect of OC group on this dependent measure, nor an interaction between OC group and feedback condition. (see Fig. 4).

In line with the SPIS model, we predicted that high OC participants will be more affected than low OC participants by the false feedback due to their attenuated access to proprioceptive information and increased compensatory reliance on external feedback. To examine the effects of OC tendencies and training feedback on reaching distance error in the after-effects trials we conducted a 2 (OC tendencies: high vs. low) X 2 (feedback: normal vs. false) mixed-design analysis of variance (ANOVA) (see Table 1 and Fig. 5). As expected, participants' final position error (distance in cm from the target location) was significantly greater after training with false feedback ($M = 3.29$ cm, $SD = 1.19$ cm) than after training with valid feedback ($M = 2.42$ cm, $SD = 1.11$ cm), $F(1, 66) = 78.11$, $p < .001$, η_p^2=0.542. More importantly, consistent with our hypothesis, the two-way interaction of feedback training condition and OC tendencies was significant, $F(1, 66) = 8.64$, $p = .005$, η_p^2=0.116. Follow-up analyses indicated that after false feedback training, high OC participants' final position error ($M_{High\ OC} = 3.59$ cm, $SD_{High\ OC} = 1.29$ cm) was significantly greater then low OC participants' error ($M_{Low\ OC} = 2.98$ cm, $SD_{Low\ OC} = 1.10$ cm) ($F(1, 66) = 10.84$, $p = .002$, η_p^2=0.141), while after valid feedback training there was no significant difference between the groups ($M_{High\ OC} = 2.44$ cm, $SD_{High\ OC} = 1.09$ cm; $M_{Low\ OC} = 2.40$ cm, $SD_{Low\ OC} = 1.13$ cm in the high and low OC groups, respectively), $F(1, 66) = 1.19$, $p = .28$. There was no interaction between OC group, feedback condition and reaching direction ($p = .25$).

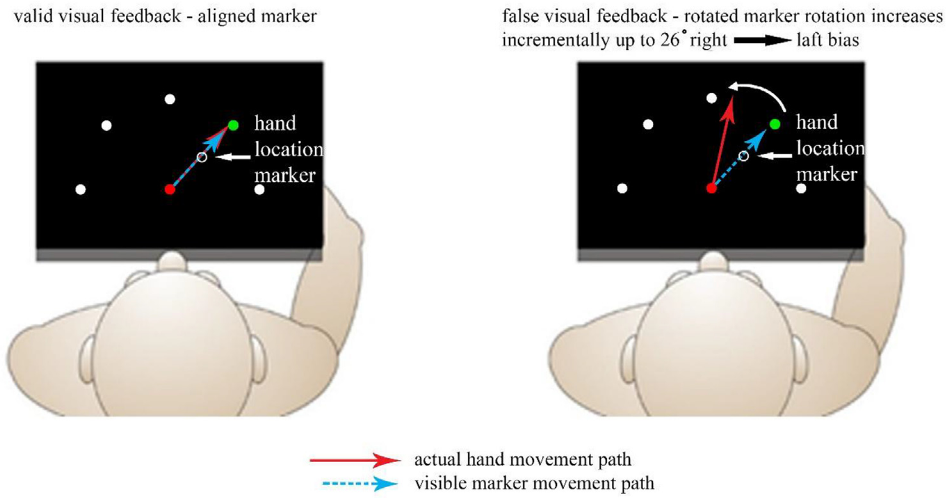

Fig. 2. Visuo-motor reach adaptation Training task setup in the valid feedback condition (left) and false feedback condition (right).

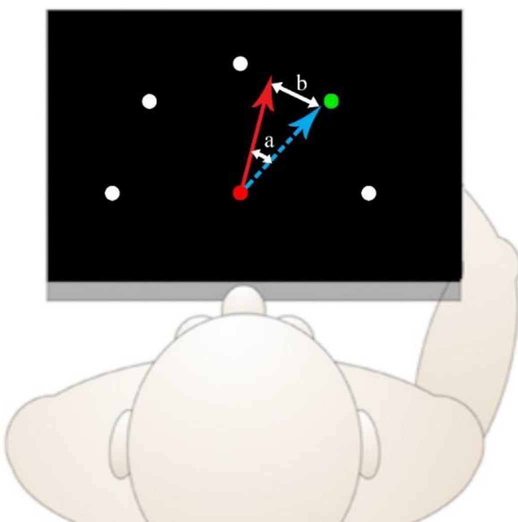

Fig. 3. Error measures: a. directional error. b. final position error.

Due to the larger ratio of women in the high OC group compared to the low OC group (79% vs. 53% respectively), we also looked at the performance of the female participants only, in order to rule out the possibility that the above-mentioned interaction could be confounded by sex differences. The analysis revealed that the interaction of OC

Table 1
Mean accuracy of OC groups by feedback training.

Accuracy measure	After valid feedback				After false feedback			
	Low	SD	High	SD	Low	SD	High	SD
Final position error (cm)	2.41	1.23	2.44	1.15	2.98	1.19	3.59	1.41
Initial angular error degrees	2.32	4.42	2.40	4.43	11.31	4.92	12.11	4.25

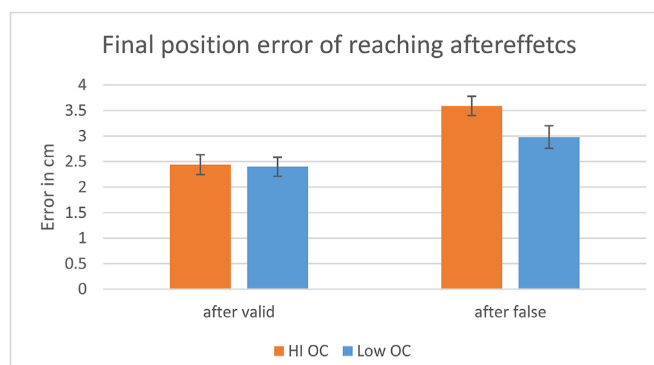

Fig. 5. Accuracy of final position for each type of feedback for each OC group. Error bars represent standard errors.

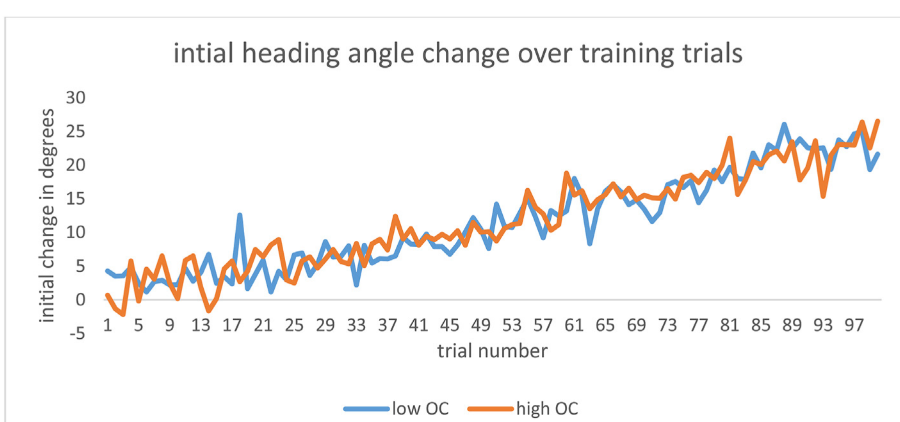

Fig. 4. Initial heading angle in the false feedback block by trial each OC group.

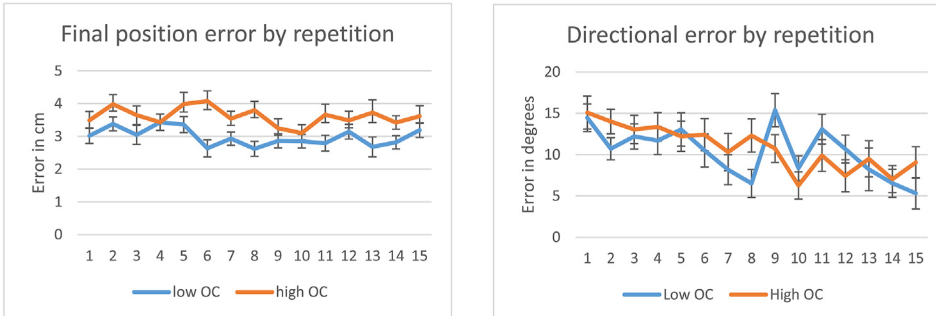

Fig. 6. Accuracy measures by repetition in the false feedback after-effects block for each OC group by final position error (left) and by directional error (right). Error bars represent standard errors.

group and feedback condition remained significant $F(1, 43) = 8.317$, $p = .006$, η_p^2=0.162 (we were unable to repeat the same analysis for men only, as there were only seven high OC participants among the men).

To determine if the final position error declined over trials, we calculated for each participant the slope of the final position error as a function of trial number (See Fig. 6 left) and tested whether this slope was different from zero using a single-sample t-test. The slope of the average final position errors across trials ($M = -0.02$, $SD = 0.10$) was not significantly different from zero $t(67) = -1.61$, $p = .113$. In addition, there was no difference between slopes of high and low OC participants ($M_{High\ OC} = -0.024$, $SD_{High\ OC} = 0.86$, $M_{Low\ OC} = -0.16$, $SD_{Low\ OC} = 1.21$), $t(66) = -0.303$, $p = .763$.

We also examined the effects of OC tendencies and training feedback condition on the directional error (the angular difference between the initial heading angle and a straight line connecting the initial and the target positions), as a dependent measure targeting specifically the adaptation to the trajectory of the false feedback. We conducted this analysis for the after-effects trials in a 2 (OC tendencies: high vs. low) X 2 (feedback: valid vs. false) mixed-design ANOVA (see Table 1). Participants' average directional reaching error (difference in degrees from the target location) remained significantly shifted (CCW) after training with false feedback ($M = 10.52°$, $SD = 3.90°$) compared to after training with valid feedback ($M = 2.35°$, $SD = 3.36°$), $F(1, 66) = 472.13$, $p < .001$, η_p^2=0.877. Contrary to our hypothesis and the above-mentioned finding regarding reaching error, in the directional error there was no interaction between feedback training condition and OC tendencies (p = .569). In contrast to the distance error, the directional error did decline over the successive trials of the after-effects block, with significant negative slopes (See Fig. 6 right), $t(67) = -5.434$, $p < .001$. Again, there was no difference between OC groups in error decay rate, ($M_{High\ OC} = -0.519$, $SD_{High\ OC} = 0.606$, $M_{Low\ OC} = -0.388$, $SD_{Low\ OC} = 0.766$), $t(66) = -0.776$, $p = .440$.

4. Discussion

The present study examined the impact of false visual feedback on hand reaching in individuals with high and low OC tendencies. In accordance with our hypothesis, after training with false feedback, high OC participants demonstrated a greater decline in the accuracy of the final position of their hand reaches (after-effects trials) compared to low OC participants. Unexpectedly, this difference was found only for the errors in the final hand position and not for the directional errors. Overall, the accuracy of hand reaches was lower in both groups after training with false feedback, compared to valid feedback. This was true for both reaching final position errors (the absolute distance from the final position to the target) and directional errors (the initial angular error).

The directional adaptation to the rotated feedback of high and low OC groups was similar in both training trials and after-effects trials, which suggests that both groups adapted similarly to the false feedback. In contrast, the behavioral/functional impact of the false feedback on achieving the goal of the task was different for high and low OC individuals such that, in the after-effects trials, the false feedback impaired the final position accuracy of high OC participants more than that of low OC participants.

Prior research on reaching movements has found that final position (absolute distance from target) and directional errors (trajectory of the hand) tend to be independent of each other, suggesting that they represent the outcome of separate processes (e.g., Gordon, Cooper, Ghilardi, & Ghez, 1994; Krakauer et al., 2000; Scheidt & Ghez, 2007; Vindras & Viviani, 1998). Scheidt and Ghez (2007), for example, found only very minimal transfer between tasks involving rotation of final position and rotation of trajectory. Separation of final position from direction was also apparent in our results, as high and low OC participants showed a similar decay rate across trials of their directional errors, but not of their distance errors.

Controlling movement direction is believed to depend on establishing a certain pattern of muscle activation. This pattern sets the relative amounts by which different muscles must be activated in order to move the hand in a given direction. In contrast, the distance, or final position of the hand, is believed to depend on the degree or intensity of activation of the muscles involved in performing this movement (Gordon, Ghilardi, Cooper, & Ghez, 1994). The final position controller is considered to also have a compensatory role in correcting errors, due to large variations in the initial direction of the movement. These corrections depend on proprioceptive signals from muscle stretch receptors (Gordon et al., 1994; Scheidt & Ghez, 2007; Vindras, Desmurget, & Viviani, 2005). In our after-effects task proprioceptive cues were central, as in the absence of visual feedback, participants had to depend mainly on these cues to compensate for the induced spatial distortion.

A plausible explanation to our results is that after training with false feedback, high OC participants, although having similar directional errors to the low OC participants, had less access to their proprioceptive signals. This might have limited their ability to compensate for the impact of the directional error on the final hand position in the after-effects trials. This account is consistent with the Seeking Proxies for Internal States (SPIS) model of OCD (e.g., Lazarov et al., 2014; Liberman & Dar, 2009), which postulates attenuated access to internal states in OCD. Specifically, our results accord with previous findings of reduced accuracy in muscle tensing in OC individuals (Lazarov et al., 2012a, b, 2014; Zhang et al., 2017), as well as a reduced gain in accuracy from active compared to passive head repositioning (Ezrati et al., 2018). Taken together, these findings suggest an attenuated access to proprioceptive information on actual muscle state (tension and stretch) in high OC participants. Moreover, proprioceptive motor information is considered one of the building blocks of the sense of agency (e.g., Synofzik et al., 2013; Tsakiris et al., 2006). Hence, this body of findings may contribute to our understanding of the diminished sense of agency in OCD, which was suggested in several recent studies (Belayachi & Van der Linden, 2010; Gentsch, Schütz-Bosbach, Endrass, & Kathmann, 2012; Oren et al., 2017, 2016; Rossi et al., 2005; Tapal, Oren, Dar, & Eitam, 2017).

Dulude and colleagues (Dulude, O'Connor, Audet, & Bedard, 2017) recently found that compared to healthy controls, OCD patients had a stronger tendency to initiate hand movements in a rigid and non-adaptive pattern after training with inversed mirror feedback. In that study, participants traced forms on a digitizer tablet with a mirror inversion of the movement. For OCD patients (but not for control participants), the initial deviation angle that preceded the intentional re-adjustment of movement remained abnormal during the task. In other words, both our study and Dulude and colleagues' study found that OC individuals had difficulty in coping with incongruent visual feedback on their movement. However, there is a clear difference between the findings of the two studies: in our study, high and low OC participants presented similar patterns of angular adaptation, whereas in Dulude and colleagues' study (2017), OCD patients showed reduced angular adaptation, a finding that the researchers interpreted as an indication for a more rigid and less adaptive visuomotor processing style. This difference in results may stem from differences in the false feedback paradigm used in the two studies. The rotation in our task (based on Cressman & Henriques, 2009; Salomonczyk et al., 2011) was very gradual and has been suggested to activate implicit adaptive motor processes (Weiner, Hallet, & Funkenstein, 1983; Pisella et al., 2004; Redding et al., 2005), whereas the mirror inversion task used by Dulude et al. (2017) is overt and non-gradual, and accordingly considered to activate explicit motor adaptation processes (Paquet et al., 2008; Petersen, Van Mier, Fiez, & Raichle, 1998). Future research could clarify how awareness of the invalidity of the feedback might modulate its effect on the performance of OC participants. A related question is whether high OC participants (compared to low OC participants) were less sensitive to the (in)validity of the feedback they received, as one might expect based on the hypothesized attenuation of their access to internal states (Lazarov et al., 2010, 2014; Liberman & Dar, 2009) and prior findings of increased reliance on false feedback for internal sensations in OCD (Lazarov et al., 2012b, 2014, 2012a; Zhang et al., 2017).

Notably, we did not find a main effect of OC tendencies on the accuracy of performance in the absence of visual feedback. Such a main effect has been found in previous muscle tension studies (Lazarov et al., 2012b, 2014, 2015). As all after-effects trials were performed without external visual feedback, we expected that as in previous studies, high OC participants would show deficient accuracy, compared to low OC participants. This lack of overall difference between the two OC groups in our study may be due to the inclusion of an extensive training block in both feedback conditions (valid vs. false). As the valid feedback training was necessary for equating the number of blocks between the two feedback conditions, but it might have masked the potential accuracy differences between the two OC groups in the following after-effects block.

This preliminary study provides further support to the hypothesis that high OC tendencies are related to attenuation of access to internal proprioceptive signals. As the SPIS model postulates, this attenuation may lead to an increased compensatory reliance on external proxies for these internal states. More specifically, while prior findings on OCD already demonstrated the increased effect of false feedback on self-perception and judgments of internal bodily states such as muscle tensing and relaxation (Lazarov et al., 2012a,b, 2014; Zhang et al., 2017), the current work documents the impact of false feedback on actual movement performance of OC individuals.

It should be noted that the current findings were derived from an analogue sample population of non-clinical, highly functioning, largely female students. Although research with analogue samples of high and low scorers on measures of OCD were found to be highly relevant to understanding OCD (Abramowitz et al., 2014), a replication of the study with a sample of OCD patients, compared to patients diagnosed with other psychiatric disorders and healthy controls, could further establish its relevance to OCD.

Finally, while we found significant effects of false feedback on movement accuracy of high OC individuals, the locus of the proposed attenuation of access to movement-related internal cues remains unknown at present. Specifically, the current paradigm could not differentiate between attenuation of the access to sensory information, such as proprioceptive cues, and difficulties in the integration of these cues with other signals involved in active movement, such as the efferent motor information. Both sensory deficiencies (Bart, Bar-Shalita, Mansour, & Dar, 2017; Dar, Kahn, & Carmeli, 2012) and deficiencies of sensory-motor integration (Russo et al., 2014) were found to be related to OC symptoms. Therefore, future studies should attempt to exclude this possible confounding factor by assessing the accuracy of perception of proprioceptive signals separately from the production of active movement.

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Conflicts of interest

The authors declare that there is no actual or potential conflict of interest in relation to this study.

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