Investigation of motor self-monitoring deficits in schizophrenia with passivity experiences using a novel modified joint position matching paradigm

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Abstract

Numerous studies have identified deficits in the self-monitoring system that are associated with schizophrenia. However, the tasks used in the few previous studies generally involved complex cognitive processes and rarely compared between patients with and without passivity experiences (PE). Here, we examined the deficits in internal motor predictive representation in patients with and without PE, and in healthy controls using a novel paradigm which involved minimal cognitive processes. All participants completed a modified Joint Position Matching (mJPM) task, in which they were required to replicate a voluntary, a passive verbally-cued, and a passive tactile-cued movement under blinded conditions. The absolute difference between the target spot and replicated spot was measured and compared. We hypothesised that if there was a failure in the internal motor predictive representation, patients with PEs would replicate less accurately in the voluntary condition, relative to passive conditions while the healthy controls would be more accurate, and therefore significant interactions between groups and conditions would be revealed. Both healthy controls and patients without PEs replicated more accurately in the voluntary condition compared with the passive conditions. The patients with PEs were less accurate in the voluntary condition compared with the passive tactile condition. A significant interaction was observed between patients with vs. without PEs × voluntary vs. passive tactile conditions. The findings suggested the relationship between deficits in motor self-monitoring in the prediction process and PEs, thus showing the need to highlight the link between motor performance and PEs.

Keywords self-monitoring, internal feed-forward, cognitive functions, passivity experiences, schizophrenia, psychosis

Declarations

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Conflicts of interest The authors declare that they have no conflicts of interest.

Ethics approval The study procedures were approved by the Institutional Review Board of the University of Hong Kong / Hospital Authority Hong Kong West Cluster and were in inline with the Helsinki Declaration of 1975. The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008.

Consent to participate Informed consent was obtained from all individual participants included in the study.

Availability of data and material none.

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Introduction

Passivity experiences are characterised by the phenomenological experience that one's own thoughts, actions or emotions are influenced by an external actor [1], with the feeling of being controlled or created [2]. Such a phenomenon has also been described as a loss of the sense of agency. In schizophrenia, symptoms that included a sense of control, such as delusions of control, insertion of thoughts, thought withdrawal, and thought broadcasting, were often considered as PEs [3,4]. In general, delusion of control occurs in over 70% of schizophrenic patients [5], while thought disruption affect fewer patients who differ in different countries [6,7].

The dominant theory is that PEs represent a framework of deficits in the sense of agency, stemming from anomalies in the self-monitoring system [3,8]. When an action is initiated, the central nervous system normally sends the corresponding motor commands for muscular contractions (i.e., the actual state) to achieve the desired state. Parallel to this, a copy of the motor command (i.e., efference copy [EC]) is also made to compute a prediction of the motor consequences (i.e., predicted state) by the forward model. In a normal self-monitoring system, the agreement of external sensory feedback about the actual state and the predicted state in a self-initiated action enables an individual to perceive the self as the agent of the action (i.e., sense of agency). However, if there is an incongruity between the two states due to the dysfunction of the feed-forward model, individuals may perceive movement as being controlled by an external agent [3,8,9].

There is ample evidence for an association between schizophrenia and motor task deficits requiring access to the EC and the predicted state [10,11]. In a recent report, Vukadinovic [12] suggested that due to the increased striatal dopamine, the dopamine D1R-expressing in the striatum medium spiny neurons failed to receive ECs from sensory cortical and limbic areas. Such deficits have been demonstrated in tasks examining the capacity of self-monitoring. Although there were a few negative reports [13,14], positive associations were reported in the following areas of self-monitoring: motor imagery [15], anticipatory effect [4,16-18] and rapid error corrections [19-22]. However, without separating patients with and without PEs for examination, the results of all the above studies only confirmed that there was a link between general impairment of cognitive function or severity of psychotic symptoms and self-monitoring; that is, the role of PEs was undetermined.

Other studies have shown that patients with PEs also exhibited abnormalities in self-monitoring when compared with those without PEs [4,18,22-26]. However, while these studies attempted to control for the impaired cognitive function of schizophrenia by comparing patients with and without PEs [20,21], more specific cognitive functions that might moderate the performance of self-monitoring tasks, such as misattributions

[27,28] and delusional associations [29], were not considered. We are still uncertain whether the results may reflect only impediments to the performance of self-monitoring tasks and not actual deficiencies in the self-monitoring system. For example, schizophrenic patients may perform poorly in rapid error correction as due to impaired attention skills. In addition, some of the tasks used in the above-mentioned studies involved complex cognitive processes such as conscious judgment of verbal stimuli and temporal activation. Given that patients with PEs often have more deficiencies in general cognitive functions, they tend to externalise bias and use eccentric criteria in their assessment that can influence the validity of a study task.

To unequivocally show that the movements of a subject involve an internal prediction pathway via EC only, a test paradigm between self-initiated and involuntary actions without external sensory feedback should be investigated. However, since the complete elimination of external sensory feedback seems impossible in the case of involuntary action, the associated external sensory feedback should be controlled at minimal. In this study, we attempted to examine the internal motor predictive representation in patients with PEs using a modified version of the joint position matching (JPM) paradigm, which originated in the field of physiotherapy [30]. The JPM task is a well-established protocol for assessing proprioception by an unseen, involuntary tactile arm-moving replication task that can eliminate the influence of visual and vestibular information [31]. As we aimed to examine the mechanism of self-initiated action, a voluntary condition was added. Given that it is almost impossible to eliminate proprioceptive feedback, the original involuntary tactile condition was maintained, along with another newly added involuntary verbal condition, to collect data on participant's proprioceptive performance (see illustration in Figure 1).

[Figure 1]

We compared the replication accuracy between voluntary and passive (tactile and verbal) conditions in patients with PEs, without PEs and healthy controls. We hypothesised that healthy controls would demonstrate a better replication accuracy in the voluntary condition than the two passive conditions, but that such an improvement would not be demonstrated by patients with PEs. We also hypothesised that significant interactions between groups and conditions would be found, such that patients with PEs would demonstrate no difference in performance between passive and voluntary conditions, while the healthy control group would demonstrate significantly better performance in voluntary condition.

Materials and methods

Participants

This study recruited patients from the outpatient psychiatric unit of Queen Mary Hospital in Hong Kong. The inclusion criteria were patients who met the DSM-V criteria [32] for schizophrenia-spectrum disorder based on psychiatrist's clinical decision, able to provide informed consent, able to understand Cantonese and clinically stable to participate in the study. Patients recruited would undergo an assessment conducted by the research assistant using the Scale for Assessment of Positive Symptoms [SAPS] trained by the psychiatrist in the research team. Patients who reported presence of delusions of being controlled, thought insertion, thought withdrawal, and thought broadcasting within one month prior to the assessment (i.e., score 1 or above in the item 15, 17, 18 and 10 in the SAPS) would be regarded as patients with relevant symptoms (relevant patient [RP] group). Those who reported absence of relevant symptoms were regarded as the patient control in this study (patient control [PC] group). Age- and education level-matched healthy individuals with no history of SCID-defined Axis I psychotic disorder (SCID-I/NP or P W/PSY SCREEN) [33] were recruited from the general community (healthy control [HC] group). Patients and healthy individuals who had upper-limb disability or a history of substance abuse were excluded from the study. To detect a moderate interaction effect (effect size = 0.5) between the 3 groups and 3 conditions, with 80% power and an alpha level of 5%, a sample size of 30 participants (10 in each group) was required.

Procedures and design

In the modified JPM task, with their eyes covered by a piece of dark-colored towel, the subjects were instructed to move their hands between an initial and a target spot under a blinded condition. In order to balance the practicing effect with systematic bias, the subjects had to perform this movement twice in each of the three conditions: (1) voluntary, (2) passive tactile, and (3) passive verbal. The order of conditions was determined randomly.

In all conditions, the task consisted of an instruction and a replication phase. In the instruction phase, the assessor instructed the participants put the index finger of their dominant hand on a marked spot (i.e., the initial spot) on a piece of A4 paper. The initial spot was designated by the assessor and was the same for all participants in all conditions. Participants were then instructed to move their index finger to a target spot, with the instruction to move being different in the three conditions. For the *voluntary condition*, the target spot was set by the participant, who could move his/her index finger from the initial spot to a target spot of his/her choice;

this target spot was then marked on the paper by the assessor after verbal confirmation by the participant. For the *passive tactile condition*, the target spot was set by the assessor by moving the index finger of the participant. For the *verbal condition*, the assessor verbally instructed the participant to move his/her finger forward by saying "Start," and then instructed him/her when to stop by saying "Stop." After such an instructed movement, the assessor re-positioned the participant's arm so that his/her index finger was put back at the initial spot, and then the replication phase followed. In the replication phase, the participant was required to replicate the movement made during the instruction phase. The procedure is illustrated in Figure 2.

[Figure 2]

Experimental variables

The outcome measure was replication accuracy defined by the average absolute distance difference in centimeters (cm) of the two trials in each condition. The absolute distance difference was measured between the target spot and the spot of location where participants placed their finger during the replication phase. To control for the rehearsal effect on the task performance, the preparation time in milliseconds (ms) was measured with a digital stopwatch by the experimenter. The preparation time meant the time-lapse in which the assessor said '*You can start the replication when you are ready*' and before the participants started moving their fingers (Supplementary Material 1).

Other data collection

The participants' psychotic symptoms were assessed using the Scale for the Assessment of Positive Symptoms (SAPS)[34] and the Scale for the Assessment of Negative Symptoms (SANS) [35]. Extrapyramidal side effects that can directly affect motor performance were assessed using the Simpson-Angus Scale (SAS) [36]. The following neurocognitive tests were performed on all patients: a Logical Memory Test (total number of correct responses in immediate and delayed recall), a Modified Wisconsin Card-Sorting Test (M-WCST) [37] (total number of perseveration errors) and the Visual Patterns Test [38] (total number of correct patterns recalled).

Statistical analysis

The age, sex, and education level of the participants were compared using a one-way ANOVA and a chi-square test between the three groups. The severity of psychotic symptoms, extrapyramidal side effects and neurocognitive function were on compared between the two patient groups. To investigate whether replication

accuracy was associated with the patients' clinical and cognitive presentations, Pearson's correlation analysis (or Spearman's rank method correlation, if the statistical assumption was violated) was performed.

The inter-condition and inter-group comparison of the replication accuracy was conducted using a mixed-design ANOVA with a within-subjects factor of conditions (voluntary, passive verbal, passive tactile) and a between-subject factor of groups (RP, PC, and HC). Post-hoc analyses were performed to identify significant pairwise differences between groups and between conditions, as well as interaction effects of groups with conditions. The pair of conditions examined were: (i) voluntary vs. passive tactile and (ii) voluntary vs. passive verbal. The effect size partial eta squared (η_p^2) was also calculated. The Benjamini-Hochberg procedure with a false discovery rate (FDR) (q-value) of 5% was used to handle the problem of multiple testing [39]. The interaction effects in the two patient groups were also computed with adjustments for the SANS score and SAPS score after excluding PEs, which differed significantly between two patient groups.

Results

Demographic, clinical and cognitive characteristics

The study recruited 39 patients (22 men; mean age 32.0 ± 12.4 years) and 25 healthy individuals (12 men; mean age 31.3 ± 8.4 years). This study only included 35 patients and 23 healthy individuals whose performance did not lie 1.5 interquartile rage above the third quartile or below the first quartile. Of all 35 patients, 18 (51.4%) had PEs in the last month (RP group; 8 men; mean age 32.3 ± 12.5 years) and 17 (48.6%) had no PEs (PC group; 14 men; mean age 31.7 ± 15.7 years). The mean year of education was 14.3 ± 2.1 for the RP group, 15.0 ± 2.7 for the PC group and 14.0 ± 1.9 for the HC group. The demographic characteristics were not significantly different between the three groups. The mean score of PEs was 12.5 ± 8.7 for the RP group. The RP group showed more severe overall positive (SAPS: 25.0 ± 13.8 vs. 10.8 ± 8.8, $p < .001$, $ES = 1.219$) and negative symptoms (SANS 14.0 ± 15.2 vs. 5.3 ± 17.4, $p = .007$, $ES = 0.533$) than the PC group (Table 1). All patients showed a low level of extrapyramidal motor disability and no group difference was found (RP: 1.6 ± 2.6; PC: 1.7 ± 2.5). In addition, no statistically significant difference in the neurocognitive characteristics was observed between the RP and PC groups (Table 1).

[Table 1]

Replication accuracy

A significant overall interaction was observed between all experimental groups and conditions: F (3.448, 94.816) = 5.653, $p < .001$, $\eta_p^2 = .171$. Pairwise post-hoc analyses showed that the replication accuracy in the RP group was worse in the voluntary condition (2.08 ± 0.55 cm) than in the passive tactile condition (1.74 ± 0.70 cm), with statistical significance (FDR corrected $p = .04$, $ES = 0.646$) (Figure 2). In the PC group, the replication accuracy was significantly better in the voluntary condition (1.68 ± 0.43 cm) than in both passive conditions (tactile: 2.13 ± 0.57 cm, FDR corrected $p = .02$, $ES = 0.726$; verbal: 2.13 ± 0.91 cm, FDR corrected $p = .04$, $ES = 0.457$)(Figure 3). Participants in the HC group also performed significantly better in the voluntary condition (1.22 ± 0.51 cm) than in both passive conditions (tactile: 1.87 ± 0.53 cm, FDR corrected $p < .001$, $ES = 1.085$; verbal: 1.56 ± 0.58 cm, FDR corrected $p = .049$, $ES = 0.510$)(Figure 3). Differences between groups were observed in the voluntary and the passive verbal condition.The poorest is the RP group, followed by the PC group and then the HC group (all FDR corrected $p < .05$, ES ranged from 0.810 to 1.621). The performance in the passive verbal condition in the PC group was significantly higher than in the HC group (FDR corrected $p = .04$; $ES = 0.747$). None of the replication accuracy was found to be associated with the symptom scores (Supplementary Material 2).

[Figure 2]

Further analysis revealed that significant interactions existed in the RP vs. HC groups, with the following conditions of replication accuracy: (1) voluntary vs. tactile: F (1, 39) = 31.085, $p < .001$, $\eta_p^2 = .444$; (2) voluntary vs. verbal: F (1, 39) = 10.770, $p = .002$, $\eta_p^2 = .216$. After adjusting for score of SANS and other positive symptoms, a significant interaction was also found between the two patient groups and the voluntary vs. passive tactile conditions: F (1, 31) = 15.592, $p < .001$, $\eta_p^2 = .335$. Similar significant interaction was also observedin the voluntary vs. passive verbal conditions between two patient groups: F (1, 31) = 7.925, $p = .008$, $\eta_p^2 = .204$.

Discussion

In this study, we demonstrated the deficits in the self-monitoring systems of schizophrenic patients may be associated with PE, which was consistent with the results of previous literature [18,21-24,40,41]. Our study is one of the few to compare self-monitoring performance between patients with and without PEs [18,22-24]. Most importantly, this is also one of the very few studies that has attempted to minimise the involvement of cognitive processes in experimental tasks of self-monitoring [42].

Self-monitoring deficit in schizophrenia and PEs

Although we did not find any improved replication accuracy in the voluntary condition compared to the two passive conditions in patients with PEs, we unexpectedly found that they performed worse in the voluntary condition. Since patients without PEs also showed an improvement in the voluntary condition, we suggested that this difference could be due to the presence of PEs related to deficit in the internal motor predictive representation in the self-monitoring system. The existence of more pronounced deficits in patients with PEs is also consistent with the literature showing that PEs are associated with the deficit of self-monitoring [18,22,24]. With control for potential cognitive confounders in the statistical analysis, in addition to the minimal involvement of cognitive processes in the paradigm, we believe that such a deficit is due to an actual impairment of these patients' self-monitoring systems, not their inability to perform self-monitoring tasks.

Self-monitoring deficit in schizophrenia and psychotic symptoms

While deficits in self-monitoring and the SAPS score were previously described as positively correlated [40], this association was not observed in the current study. No positive correlation between experimental performance and the level of PEs was observed, suggesting that the effect of PEs on self-monitoring is an on-off relationship rather than a dose relationship. In other words, the presence of PEs may mean the absence of an EC pathway, which in this study may lead to poorer experimental performance. Despite a similar demographic data (such as age, sex, and years of education), we unexpectedly found that the SANS score differed between the two patient groups. Indeed, the positive correlation between SAPS and SANS was also reported in a large-scale study previously [43]. After controlling for the score of the SANS and other positive symptoms statistically, we found the interaction between the two patient groups and the voluntary and passive tactile conditions persisted. Therefore, we believe that the distinctive pattern of replication accuracy in patients with PEs could be related to the presence of PEs and eliminated the possibility that the difference was due to the differences in negative symptoms or illness severity.

Self-monitoring deficit in schizophrenia and cognitive symptoms

In this study, we attempted to investigate the self-monitoring deficit in schizophrenia by ruling out the effects of impaired cognitive function in schizophrenia on task performance. Considering that the current paradigm still requires a certain amount of mnemonic and executive processing (majorly the short-term motor memory) typically associated with the performance of self-monitoring tasks [22-24,41], we compared the short- and long-term logical memory, spatial memory and executive function between groups, and examined their correlations

with experimental variables. Although previous studies also reported patients with different executive functions can differentiate their psychopathology [44,45], the insignificant findings in the current study suggested the irrelevance of these cognitive processes to the tasks used. Although it is possible that healthy individuals may be more attentive to the instructed movement and are therefore better able to rehearse the replication process before initiating the replication, thereby performing more accurate replications, our findings about preparation time suggest that the reheasal effect is actually minimal and possibly non-influential.

Self-monitoring deficits in schizophrenia and motor abnormalities

The performance of motor self-monitoring tasks can be mediated by low-level physiological problems, such as inaccurate muscle signals or poor muscle control. Motor abnormalities in schizophrenia, such as tremors and tics, are typically side-effects of medication and are correlated with positive symptoms [46,47]. In this study, we did not detect more severe extrapyramidal side-effects in the SAS, although patients with PEs had more severe positive and negative symptoms. While the origin of motor problems could be at a neurological level specific to certain motor sequence and coordination problems (such a hypothesis is supported by previous studies that have found a positive correlation between neurological soft-signs and positive symptoms [48,49]), our data is insufficient to clarify this phenomenon. Therefore, future studies are warranted to investigate the role of neurological soft-signs in self-monitoring.

Limitations

Our study findings confirmed the hypothesis that PEs are associated with self-monitoring deficits. However, several methodological and theoretical limitations should be acknowledged. From a methodological point of view, firstly, the modified JPM task is a novel paradigm that lacks validity verification. However, as the interpretation of the performance of the task was rather intuitive, and we included a group of patients without PEs as a comparison group, we believe that our findings are reliable and valid. Yet, further studies with neuroimaging investigation should be warranted. Secondly, the inconsistent results between passive verbal and tactile conditions suggest that there is a radical difference between the verbal and tactile movements. The fact that the performance of healthy controls in passive verbal conditions was intermediate between their performance in voluntary and passive tactile conditions suggested that the verbally-cued hand movement may not be entirely passive, and the passive tactile condition deems more suitable as a control condition. Indeed, two recent neuroimaging studies demonstrated distinctive brain activity (e.g., cerebellum and middle temporal gyrus) in active and passive hand movements in healthy subjects [50,51]. These investigations may need to be

extended to the clinical context. Thirdly, the measurement precision might be compromised by the use of only pen and paper instead of digital instruments. However, when we tried to develop a paradigm that could be easily adopted in the clinical and community environment, a simpler method was used. Finally, there was no information on the use of antipsychotics in the two patient groups and the cognitive performance of healthy individuals. Since antipsychotics with strong dopamine antagonism may affect JPM performance when incorporating EC into dopamine-mediated pathways [52,53], further studies should be conducted to confirm that the use of antipsychotics is not a disruptive factor in group effects. Despite a similar pattern between performance of the PC and HC groups, further study that also collect cognitive performance among the PC group should inform better understanding on the role of cognitive process on the performance of the experiments.

From a theoretical point of view, we have found a clear link between PEs and deficits in self-regulation, but the causal link between these phenomena remains unclear. Besides, action awareness perhaps is only one of the many other factors that contribute to the presentation of PEs. Further studies shall consider taking into account the role of emotional, physical events and psychosocial factors such as adversity in the investigation of deficits of self-monitoring. Finally, the manifestation of self-monitoring deficits is somewhat unconscious, which is radically different from the altered consciousness generated by PEs, in which patients can feel the bizarre experience directly. More advanced methods such as neuroimaging will be needed to examine these deficits at a deeper level to confirm that they have the same mechanism.

Implication

Clarification of the psychopathology of self-monitoring deficits can provide some insights into clinical treatment. In this study, we further confirmed the crucial role of the motor-monitoring system in the symptomatology of schizophrenia. The task we used in this study was designed to be simple and practical for use outside experimental settings, as it involved only pen and paper. Thus, once this task is validated in a large-scale study, it will be convenient for assessing self-monitoring deficits in any setting, including clinical and community settings.

Like previous studies, this study had a cross-sectional design. To improve our understanding of the relationship between the development of illness and deficits of self-monitoring, future studies should adopt a longitudinal approach and collect more information on the course of illness, the duration of illness, the duration of non-treatment, onset age, and other factors. Our findings could be extended as an assessment to potentially novel

interventions that improve the efference-copy based predictions in schizophrenia spectrum disorders, such as transcranial direct current stimulation [54].

Conclusion

In this study, we used a novel paradigm that showed minimal cognitive stress and confirmed and clarified the findings of previous studies that motor self-monitoring deficits are associated with PEs in schizophrenia. Future studies should focus on the nature of these motor problems, which can be strongly associated with the symptomatology of schizophrenia.

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Table 1. Patients' clinical and neurocognitive characteristics.

Variables	RP group (n = 18) Mean (SD)	PC group (n = 17) Mean (SD)
Passivity experience (SAPS item 15, 17-19)	12.4 (8.7) [a]	0.0 (0.0) [a]
Other positive symptoms (SAPS item 1−14, 16, 20−34)	12.6 (6.9)	10.8 (8.8)
Overall positive symptoms (SAPS total)	25.0 (13.8) [b]	10.8 (8.8) [b]
Overall negative symptoms (SANS total)	14.0 (15.2) [c]	5.3 (17.4) [c]
Extrapyramidal effect (SAS)	1.6 (2.6)	1.7 (2.5)
Logical memory (immediate recall)	10.2 (3.9)	11.0 (4.1)
Logical memory (delayed recall)	8.4 (5.7)	9.6 (5.4)
M-WCST perseveration error	7.7 (5.7)	9.8 (5.1)
Visual patterns test	8.9 (3.5)	10.5 (4.6)

RP = relevant patient; PC = patient control; SD = standard deviation; SAPS = Scale for the Assessment of Positive Symptoms; SANS = Scale for the Assessment of Negative Symptoms; M-WCST = Modified Wisconsin Card-Scoring Test.

[a] The level of passivity experience was significantly different between the RP and PC groups ($p < .001$).

[b] The level of overall positive symptoms was significantly different between the RP and PC groups ($p < .001$).

[c] The level of overall negative symptoms was significantly different between the RP and PC groups ($p = .007$).

Figure 1. Illustration of the cognitive processes underlie actions replication.

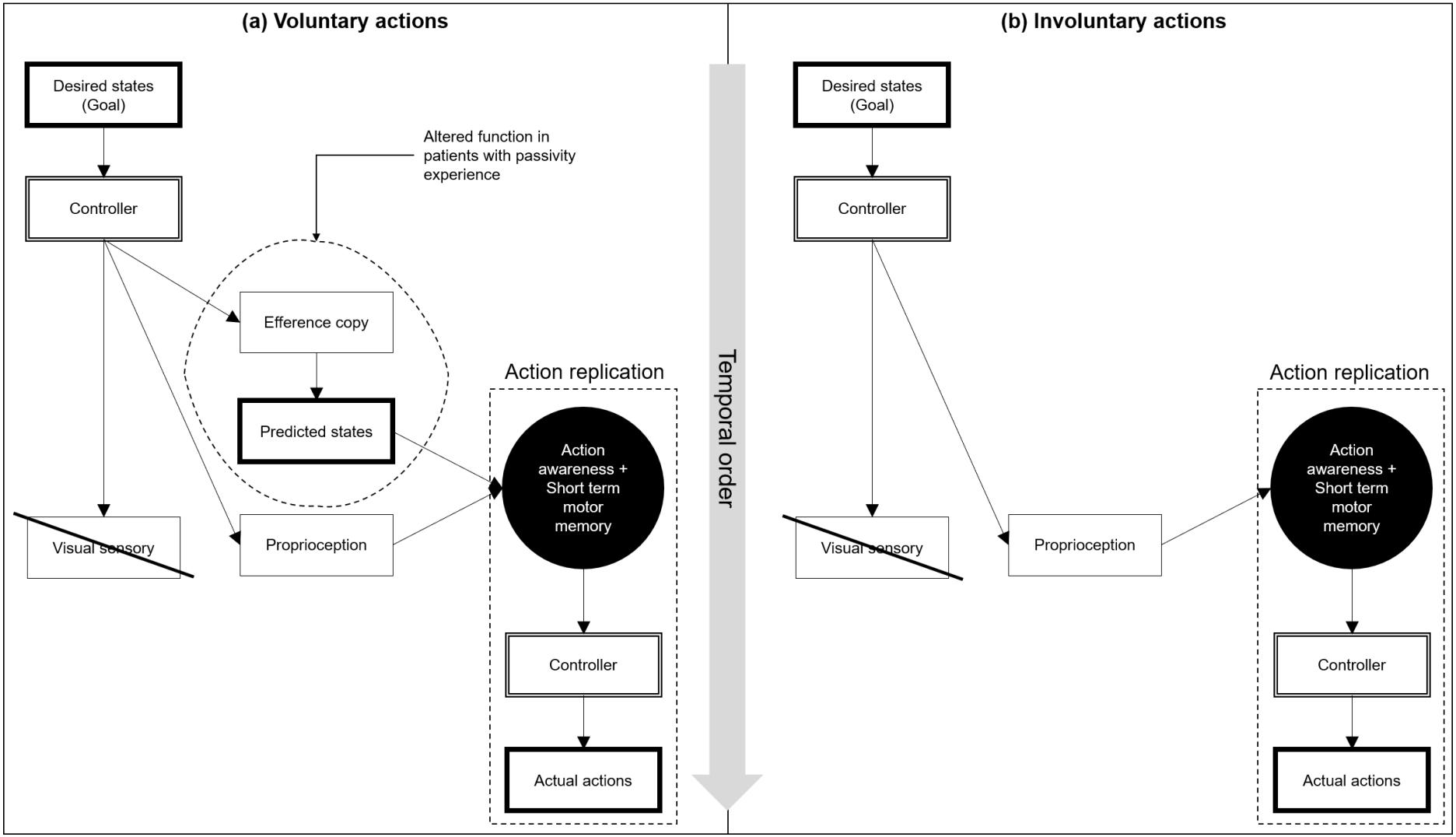
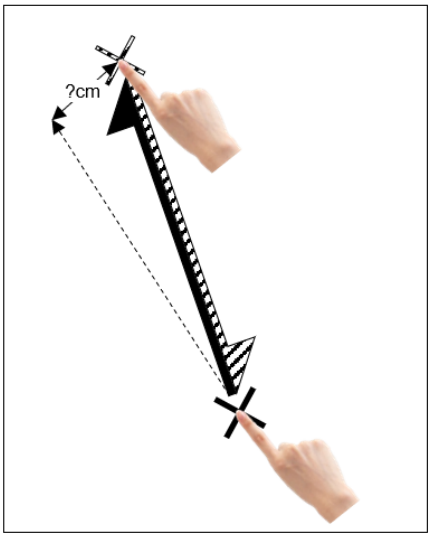


Figure 2. Illustration of the modified joint position matching tasks.



Instructed movement (movement to be replicated)

Movement in which the assessor brings the participant's index finger from the target spot back to the initial spot at the end of the instruction phase

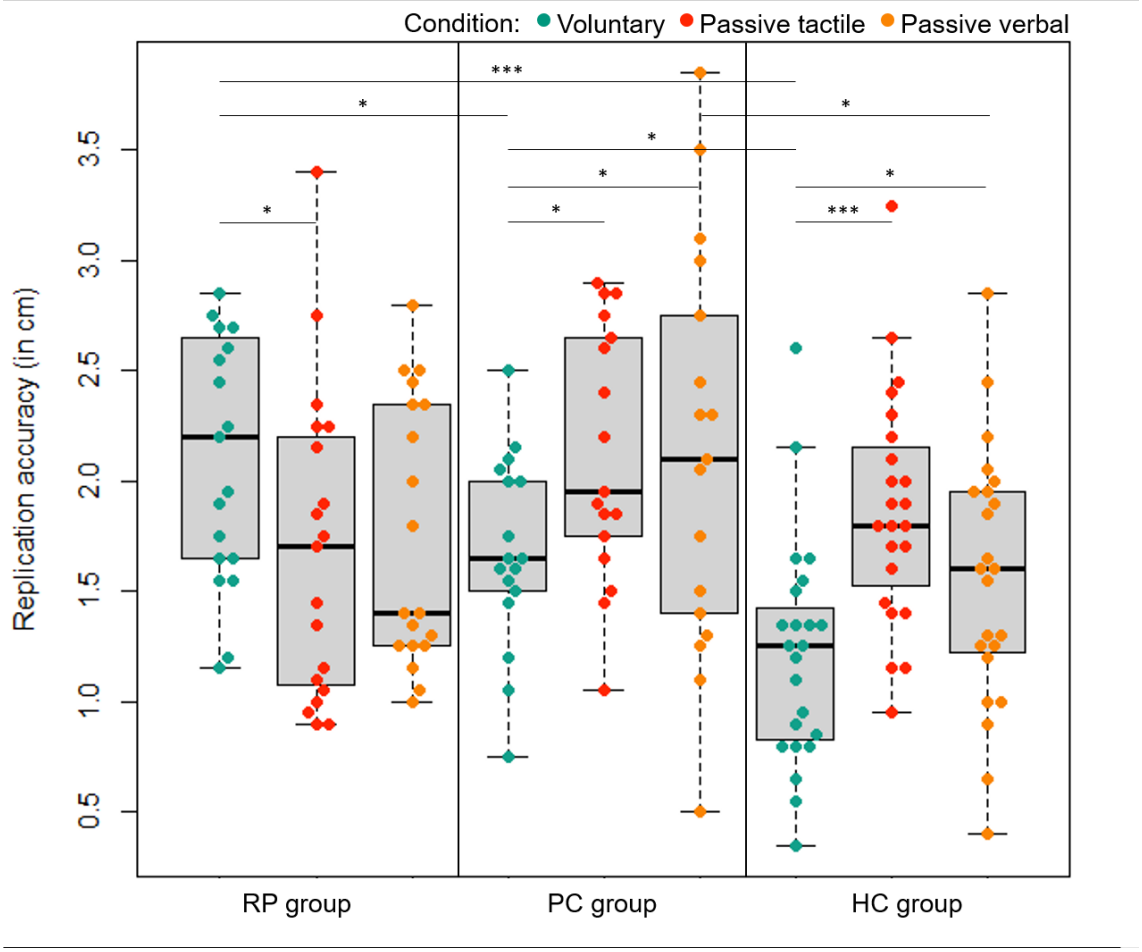
Possible movement the participant made during the replication phase

Initial spot (fixed)

Target spot (different for the three conditions)

Conditions	Instructed movement
Voluntary	Decided by the participant
Passive Tactile	Performed by the assessor through moving the participant's index finger
Passive Verbal	Verbally instructed by the assessor (from "Start" to "Stop")

Figure 3. Comparison of the experimental groups' replication accuracy in the voluntary and each of the passive conditions.



FDR corrected *p*: * < .05; ** < .01; *** < .001. Error bar denotes the 95% confidence interval.
Group (all) x condition (all) interaction: $F(3.448, 94.816) = 5.653$, $p < .001$, $\eta_p^2 = .171$.
Group (RP vs. PC) x condition (voluntary vs. tactile) interaction: $F(1, 33) = 16.438$, $p < .001$, $\eta_p^2 = .332$.
Group (RP vs. PC) x condition (voluntary vs. verbal) interaction: $F(1, 33) = 7.725$, $p = .009$, $\eta_p^2 = .190$.
Group (RP vs. HC) x condition (voluntary vs. tactile) interaction: $F(1, 39) = 31.085$, $p < .001$, $\eta_p^2 = .444$.
Group (RP vs. HC) x condition (voluntary vs. verbal) interaction: $F(1, 39) = 10.770$, $p = .002$, $\eta_p^2 = .216$.
Adjusted group (RP vs. PC) x condition (voluntary vs. tactile) interaction: $F(1, 31) = 15.592$, $p < .001$, $\eta_p^2 = .335$.
Adjusted group (RP vs. PC) x condition (voluntary vs. verbal) interaction: $F(1, 31) = 7.925$, $p = .008$, $\eta_p^2 = .204$.

Supplementary Material 1. Preparation time for replication action initiation.

Conditions	Mean preparation time for RP group* (ms) [SD]	Mean reparation time for PC group $^{\Delta}$ (ms) [SD]	*p* value$^{\#}$
Voluntary	500 [184]	471 [135]	.64
Passive Tactile	529 [175]	489 [191]	.42
Passive Verbal	520 [172]	510 [179]	.85

RP = relevant patient; PC = patient control; SD = standard deviation; $^{\#}$ an independent samples *t*-test was used; * n = 20; $^{\Delta}$ n = 19.

Supplementary Material 2. Correlation coefficients between replication accuracy and clinical and cognitive variables in patients.

	Conditions								
	Voluntary			Passive Tactile			Passive verbal		
Variables	**All**	**RP**	**PC**	**All**	**RP**	**PC**	**All**	**RP**	**PC**
Clinical									
Passivity experience (PE)(SAPS item 15, 17-19)	.332	.046	n/a	−.244	.100	n/a	−.229	−.232	n/a
Other positive symptoms (SAPS item 1−14, 16, 20−34)	.133	−077	.310	.159	.108	.328	.141	−.043	.299
Overall positive symptoms (SAPS total)	.276	−.044	.310	.052	.112	.328	−.015	−.183	.299
Overall negative symptoms (SANS total)	.084	.080	−.285	−.070	-.019	.060	.082	−.079	.416
Cognitive									
Logical memory (immediate recall)	−.164	−.171	−.096	.210	.227	.146	.103	.197	.012
Logical memory (delayed recall)	−.149	−.217	−.180	.157	.197	.144	−.076	.177	−.250
M-WCST perseveration error	−.008	.297	−.266	.123	.311	−.282	.041	.108	−.087
Visual patterns test	−.124	.151	−.270	.078	.369	−.323	.096	.063	.051

RP = relevant patient group; PC = patient control group.
n/a = correlation anaysis was not performed as all participants in the PC group had no PE.
All correlation coefficients are not statistically significant.

Supplementary material 3. Power analysis of all interaction effects.

Interaction terms	F	df	P	η_p^2	Power
Group (all) x condition (all)	5.653	3.448,94.816	<.001	.171	.959
Group (RP vs. PC) x condition (voluntary vs. tactile)	16.438	1,33	<.001	.332	.976
Group (RP vs. PC) x condition (voluntary vs. verbal)	7.725	1,33	.009	.190	.770
Group (RP vs. HC) x condition (voluntary vs. tactile)	31.085	1,39	<.001	.444	1.000
Group (RP vs. HC) x condition (voluntary vs. verbal)	10.770	1,39	.002	.216	.893
Adjusted for negative symptoms and other positive symptoms					
Group (RP vs. PC) x condition (voluntary vs. tactile)	15.592	1,31	<.001	.335	.969
Group (RP vs. PC) x condition (voluntary vs. verbal)	7.925	1,31	.008	.204	.778