Article

Hong Kong Journal of Occupational Therapy

Hong Kong Journal of Occupational Therapy
2018, Vol. 31(1) 22–29

DOI: 10.1177/1569186118759610
journals.sagepub.com/home/hjo
SAGE

Effects of object size and distance on reaching kinematics in patients with schizophrenia

Shu-Mei Wang[1], Li-Chieh Kuo[2], Wen-Chen Ouyang[3], Hsiao-Man Hsu[2] and Hui-Ing Ma[2]

Abstract

Background/Objective: Patients with schizophrenia not only have psychiatric symptoms, but also have movement problems, which might also be associated with their reduced quality of life. Little is known about how to improve their movement performance for patients. Manipulating object size and distance is common in occupational therapy practice to evaluate and optimize reaching performance in patients with physical disabilities, but effects of the manipulation in patients with schizophrenia remain unclear. The purpose of this study was to examine whether object size and distance could change performance of reaching kinematics in patients with mild schizophrenia.

Methods: Twenty-nine patients with mild schizophrenia and 15 age- and gender-matched healthy controls were required to reach for, as quickly as possible, a small or large object that was placed at a near or far distance. We measured movement time, peak velocity, path length ratio, percentage of time to peak velocity, and movement units to infer movement speed, forcefulness, spatial efficiency (directness), control strategies, and smoothness.

Results: Patients' reaching movements were slower ($p = .017$) and less direct ($p = .007$) than those of controls. A larger object induced faster ($p = .016$), more preprogrammed ($p = .018$), and more forceful ($p = .010$) movements in patients. A farther object induced slower, more feedback dependent, but more forceful and more direct movements (all $p < .001$).

Conclusion: The results of kinematic deficiencies suggest the need of movement training for patients with mild schizophrenia. Occupational therapists may grade or adapt reaching activities by changing object size and distance to enhance movement performance in patients with schizophrenia.

Keywords

Activity grading, distance perception, occupational therapy, reaching kinematics, schizophrenia, size perception

Introduction

Patients with schizophrenia not only have symptoms of reality distortion (Arango & Carpenter, 2011), but also have movement disorders, such as bradykinesia and tremor (Haddad & Mattay, 2011; Pappa & Dazzan, 2009; Rogers, 1992), which are correlated with poor remission of psychotic symptoms (Chatterjee et al., 1995) and reduced quality of life (Hofer et al., 2004; Kao, Liu, Chou, & Cheng, 2011). Despite detrimental influences of movement abnormalities, little is known about how to provide movement training for patients with schizophrenia. Review studies (Shenton, Dickey, Frumin, & McCarley, 2001; Torrey, 2002) provide evidence that patients have basal ganglia abnormalities, which may impair their ability to coordinate different motor commands in the brain and to execute movements efficiently (Alberts, Saling, Adler, & Stelmach, 2000; Canning, 2010; Castiello, Bennett, Bonfiglioli, Lim, & Peppard, 1999). These reports necessitate further studies to identify detailed kinematic features

[1]The Hong Kong Polytechnic University, Hong Kong
[2]National Cheng Kung University, Taiwan
[3]Lu-Tung Christian Hospital, Taiwan

Corresponding author:
Hui-Ing Ma, Institute of Allied Health Sciences, National Cheng Kung University, 1 University Road, Tainan 70101, Taiwan.
Email: huingma@mail.ncku.edu.tw

of movements in patients and to develop appropriate rehabilitation strategies.

Occupational therapists commonly grade reaching tasks by changing object size and distance in therapeutic protocols (American Occupational Therapy Association, 2014; Newell & Valvano, 1998). However, whether this kind of grading could be applied to movement training for patients with schizophrenia remains unclear. According to Fitts' law (1954), object size and distance determine the task difficulty that has a robust mathematical relationship with the participant's movement time. Studies in neurologically intact adults (Adam, 1992; Fitts, 1954; Milner & Ijaz, 1990) indicated that when the participant moved the hand to an object, a smaller or farther object induced a longer movement time. Effects of object size and distance on movements have also been found in patients with various neurological disorders, such as Parkinson's disease (Alberts et al., 2000; Castiello, Stelmach, & Lieberman, 1993), which involves basal ganglia dysfunction. Given that schizophrenia also involves basal ganglia abnormalities (Shenton et al., 2001; Torrey, 2002), it is possible that object size and distance could affect movement patterns in patients. This investigation may provide occupational therapists with suggested guidelines that could be employed to design movement training activities for patients with schizophrenia.

The purpose of this study was to investigate whether object size and distance would change performance of reaching kinematics in patients with mild schizophrenia and healthy controls. Reaching is basic in daily activities and underpins human abilities to interact with the environment. Another reason why we analyzed reaching movements is that reaching represents a fundamental but skilled movement that is sensitive to disease impacts (Platz, Prass, Denzler, Bock, & Mauritz, 1999). Kinematic analysis was used to describe spatial and temporal characteristics of movements so that we could detect patients' deficits in motor control and identify how object size and distance changed movement organization in patients. We hypothesized that patients with mild schizophrenia would have kinematic deficiencies compared with healthy controls. Additionally, we hypothesized that object size and distance would change performance of reaching kinematics in patients. This study informs us of which parts of kinematic performance are deficient in patients. This insight is important because a clear understanding of patients' movement characteristics makes effective intervention possible. Object size and distance are factors commonly used to grade difficulty of motor training for clients with physical dysfunction in clinical practice of occupational therapy. Occupational therapists are familiar with the manipulation of these two factors and easily incorporate them into the motor training protocols tailor made for patients with schizophrenia. The results of this study concerning effects of object size and distance on reaching kinematics may help practitioners provide effective and evidence-based motor training to improve movement performance in patients with schizophrenia.

Methods

Study design

A three-way mixed design with one independent variable (group) and two repeated variables (object size and distance) was used. The four object conditions were formed by crossing object size (small versus large) and object distance (near versus far). The test order of the four object conditions was counterbalanced. The Institutional Review Board of the hospital approved this study (the reference number: 09-025) and all participants provided informed consent before the study began.

Participants

Convenience sampling was used to recruit patients with mild schizophrenia from the chronic wards and day care centers of a psychiatric teaching hospital, and to recruit healthy controls from a university. Two groups of participants were age- and gender-matched. Patients with mild schizophrenia need to meet the following inclusion criteria: (1) schizophrenia or schizoaffective disorder, diagnosed by a psychiatrist using the criteria of the *Diagnostic and Statistical Manual of Mental Disorders*, 4th edition (American Psychiatric Association, 1994); (2) being clinically stable, determined by taking the same oral or injected antipsychotics for at least four weeks before the study; (3) absence of extrapyramidal motor symptoms under the criteria of the Extrapyramidal Symptom Rating Scale (Chouinard & Margolese, 2005; Chouinard, Ross-Chouinard, Annable, & Jones, 1980); a score of three in any item or a score of two in two or more items of a motor symptom domain (the parkinsonism and akathisia domain, the dystonia domain, or the dyskinesia domain) is deemed the presence of an extrapyramidal motor symptom; (4) sufficient cognitive ability to understand the experimental instructions, determined by a score above 24 on the Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975; Guo et al., 1988); (5) right-handedness by self-report; and (6) no neurological or musculoskeletal diseases, substance abuse, diabetes mellitus, or other medical conditions that would impair their hand movements. Healthy controls needed to meet inclusion criteria

(4)–(6). We used the Positive and Negative Symptom Scale (Cheng, Ho, Chang, Lan, & Hwu, 1996; Kay, Fiszbein, & Opler, 1987) to evaluate psychiatric symptom severity in patients; a higher score indicates severer symptoms.

Task setup and kinematic measurement

A cylindrical object was placed on the edge and midline of a height-adjustable table. Two object sizes were used: small (3 cm in diameter) and large (7 cm in diameter). Both objects were 1.4 cm high and weighed almost the same (small: 20.9 g; large: 21.5 g). Starting positions were set on the right side of the object and lay at near (20 cm) and far (40 cm) distances away from the object (Figure 1(a) and (b)).

A motion capture system (Qualisys AB, Gothenburg, Sweden) with six cameras and a connected personal computer was used to capture the three-dimensional movements of 0.4 cm diameter reflective markers with infrared-reflecting spheres. Three markers were separately attached to the thumbnail, index fingernail, and the third metacarpal base of each participant's right hand. Three extra markers were attached to the object to detect its movements. The cameras use diodes on the front to emit invisible infrared flashes to illuminate the reflective markers, and thus are able to capture the spatial positions of markers. The sampling rate of the cameras was set at 70 Hz. The captured data in the computer were processed using Qualisys Track Manager software and then exported to a numerical computing software (Matlab 7.1; Mathworks, Natick, MA) for kinematic calculation.

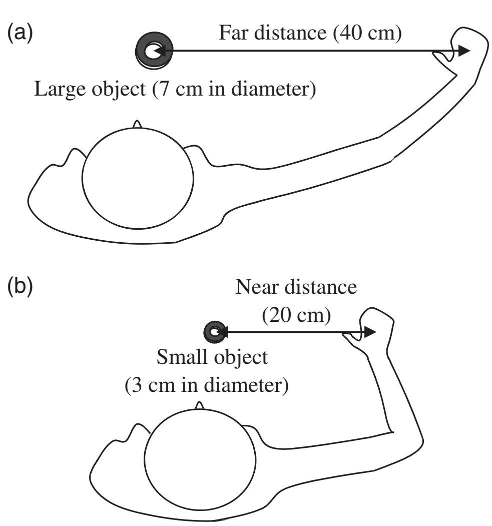

Figure 1. Setup for the reaching movement to (a) the large (7 cm in diameter) and far (40 cm away) object and to and (b) the small (3 cm in diameter) and near (20 cm away) object.

Procedures

The participant sat in front of the object and initially rested their right hand on the required starting position (Figure 1(a) and (b)). The table was adjusted to the participant's elbow height. After listening to an acoustic signal, the participant moved the right hand inward to grasp the object and lift it off the table as fast as possible. Trials during which the object slipped out of the participant's hand were not counted. Additionally, the participant was required to grasp the object with the thumb and index finger. After doing some practice trials, the participant did five successful trials for each condition with a short break between conditions.

Variable definitions

We analyzed the reaching movements in participants. *Movement onset* was defined as the time point when wrist velocity reached 5% of its peak value (Lin, Chen, Chen, Wu, & Chang, 2010; Wu, Chuang, Lin, Chen, & Tsay, 2011). *Movement end* was defined as the time point when thumb velocity reached 0 mm/s (Wang et al., 2014). Kinematic variables included *movement time*, *peak velocity*, *path length ratio*, *percentage of time to peak velocity*, and *number of movement units*, which separately represent movement speed, forcefulness at movement initiation, spatial efficiency, control strategies, and smoothness. *Movement time* is the length of time between movement onset and end. Shorter movement times reflect faster movements. *Peak velocity* is the maximum of instantaneous wrist velocity during the movement (Wang et al., 2011; Wu, Chen, Tang, Lin, & Huang, 2007). Higher peak velocities reflect greater force generation at movement initiation. *The path length ratio* is the length of the wrist path in three-dimensional space divided by the straight-line distance between the wrist onset and end positions (Kamper, McKenna-Cole, Kahn, & Reinkensmeyer, 2002; Lin et al., 2010). A lower path length ratio reflects a more direct and spatially efficient movement.

A typical reaching movement generates a single-peaked velocity profile that includes the *acceleration phase*, where the hand is under preplanned control and rapidly approaches an object, and the *deceleration phase*, where the hand is under feedback-based control to adjust the movement trajectory and thus to accurately reach the object (Elliott, Helsen, & Chua, 2001; Lin et al., 2010; Lin, Wu, Wei, Lee, & Liu, 2007). *The percentage of time to peak velocity* indicates the proportion of movement time spent on the acceleration phase (Lin et al., 2010, 2007). When a movement is more preplanned and more dependent on the feedforward control, it is predicted to spend more time on accelerating toward the object and to show a higher percentage of time to peak velocity. By contrast, when a movement relies more on visual or proprioceptive feedback to correct movement trajectories, the deceleration time is disproportionally increased, which is shown as a lower percentage of time to peak velocity (Wang et al., 2011; Wu, Wong, Lin, & Chen, 2001). *The movement unit* consists of one acceleration and one deceleration (Kluzik, Fetters, & Coryell, 1990; Wu et al., 2011). Fewer movement units indicate a smoother movement.

Data analysis

We used a three-way analysis of variance for each kinematic variable to examine group differences (patients versus healthy controls) and the effects of object size (small versus large) and object distance (near versus far). Significance was set at $p < 0.05$. We calculated an effect size, eta squared (η^2), to indicate the magnitude of the object effects and the difference between groups. η^2 values of 0.010, 0.059, and 0.138 are considered small, moderate, and large effects, respectively (Cohen, 1988).

Results

Demographic and clinical data of participants

Twenty-nine patients with mild schizophrenia and 15 healthy controls were enrolled in this study (Table 1). The participants did not differ significantly in age, gender, or scores on the Mini-Mental State Examination. Patients had significantly less education than did healthy controls.

Movement differences between patients and controls

Three-way analysis of variance showed no significant interaction effects for any kinematic variables (Tables 2 and 3). Significant group effects were found for movement time and path length ratio. Compared with healthy controls, patients had longer movement times and larger path length ratios.

Effects of object size

Significant size effects were found for movement time, peak velocity, and percentage of time to peak velocity. Compared with the small object, the large object induced a shorter movement time, a higher peak velocity, and a higher percentage of time to peak velocity.

Effects of object distance

Distance effects were significant for movement time, peak velocity, path length ratio, and percentage of time to peak velocity. Compared with the near object, the far object induced a longer movement time, a higher peak velocity, a lower path length ratio, and a lower percentage of time to peak velocity.

Discussion

To our knowledge, this is the first study that shows the significant effects of object size and distance on reaching kinematics in patients with mild schizophrenia. We found that patients had slower and less direct movements than did the healthy controls. Additionally, patients responded to changing object size and distance in a way similar to that of healthy

Table 1. Demographic and clinical characteristics of participants.

	Group[a]			
	Patients with schizophrenia	Healthy controls	Statistic	
Variables	($n = 29$)	($n = 15$)	t or χ^2	p
Demographic				
Age (years)	33.23 ± 4.64	32.02 ± 4.98	0.798	0.429
Female (n (%))	12 (41.38)	7 (46.67)	0.113	0.737
Duration of illness (years)	11.76 ± 4.76[b]	NA	NA	NA
Education (years)	12.21 ± 2.83	18.33 ± 3.24	−6.476	< 0.001
Clinical				
Chlorpromazine equivalent doses (mg/day)	482.26 ± 180.56[c]	NA	NA	NA
Mini-Mental Status Examination	28.90 ± 1.01	29.47 ± 0.74	−1.925	0.061
Positive and Negative Symptom Scale				
Positive symptoms	13.34 ± 4.43	NA	NA	NA
Negative symptoms	16.00 ± 3.00	NA	NA	NA
General psychopathology	30.93 ± 6.74	NA	NA	NA

[a]All data are means ± standard deviation, unless otherwise indicated.
[b]Because of missing records in two patients' medical charts, $n = 27$.
[c]Because of a missing record, $n = 28$.

Table 2. Descriptive statistics for movement kinematics.

	Small object		Large object	
Variables	Near Mean ± SD	Far Mean ± SD	Near Mean ± SD	Far Mean ± SD
MT (second)				
Patients	0.54 ± 0.11	0.67 ± 0.12	0.54 ± 0.11	0.65 ± 0.11
Controls	0.48 ± 0.09	0.58 ± 0.13	0.46 ± 0.10	0.56 ± 0.13
PV (mm/second)				
Patients	452.33 ± 89.52	984.73 ± 174.06	472.90 ± 84.89	999.34 ± 176.22
Controls	474.60 ± 59.30	1061.75 ± 146.15	495.18 ± 84.54	1067.84 ± 138.43
PLR				
Patients	1.15 ± 0.09	1.07 ± 0.04	1.16 ± 0.08	1.08 ± 0.04
Controls	1.11 ± 0.05	1.04 ± 0.02	1.11 ± 0.04	1.04 ± 0.02
PTPV				
Patients	0.47 ± 0.10	0.42 ± 0.07	0.49 ± 0.09	0.43 ± 0.08
Controls	0.52 ± 0.09	0.43 ± 0.07	0.53 ± 0.11	0.45 ± 0.09
NMU (unit)				
Patients	1.26 ± 0.34	1.25 ± 0.34	1.33 ± 0.36	1.21 ± 0.32
Controls	1.18 ± 0.36	1.13 ± 0.24	1.31 ± 0.42	1.13 ± 0.32

MT: movement time; NMU: number of movement units; PLR: path length ratio; PTPV: percentage of time to peak velocity; PV: peak velocity.

Table 3. Results of three-way analysis of variance for movement kinematics.

	Effect								
	Group			Object size			Object distance		
Variables	*F*	*p*	η^2	*F*	*p*	η^2	*F*	*p*	η^2
MT	6.197	0.017	0.129	6.281	0.016	0.130	121.490	<0.001	0.743
PV	1.584	0.215	0.036	7.315	0.010	0.148	1260.404	<0.001	0.968
PLR	7.936	0.007	0.159	1.126	0.295	0.026	113.798	<0.001	0.730
PTPV	1.513	0.226	0.035	6.082	0.018	0.126	68.324	<0.001	0.619
NMU	0.708	0.405	0.017	1.399	0.243	0.032	3.671	0.062	0.080

MT: movement time; NMU: number of movement units; PLR: path length ratio; PTPV: percentage of time to peak velocity; PV: peak velocity.

controls. A larger object induced faster, more preprogrammed, and more forceful reaching movements. A farther object induced slower, more feedback dependent, but more forceful and more direct movements in patients.

Kinematic deficiency in patients with schizophrenia

Reaching movements in patients with schizophrenia were slower and less direct than those in healthy controls. Our findings of impaired movement speed in patients are consistent with those in prior research (Carnahan, Elliott, & Velamoor, 1996). Our study extends earlier findings by identifying deficits in spatial efficiency. Patients with schizophrenia have basal ganglia abnormalities (Shenton et al., 2001; Torrey, 2002), which affect their ability to coordinate different motor signals from the cerebral cortex and thus cause a failure to generate temporally and spatially efficient movements (Alberts et al., 2000; Canning, 2010; Castiello et al., 1999).

Effects of object size in patients

A larger object elicited faster, more preprogrammed, and more forceful reaching movements in patients with mild schizophrenia, which agrees with prior findings in healthy adults (Adam, 1992; Fitts, 1954; MacKenzie, Marteniuk, Dugas, Liske, & Eickmeier, 1987; Milner & Ijaz, 1990). Our study extends earlier results by showing effects of object size for patients with schizophrenia. Object size is relevant to accuracy demands of movement tasks (Fitts, 1954; MacKenzie et al., 1987; Milner & Ijaz, 1990). Reaches for a smaller object require more time in the proximity of the object and more sensory feedback to make precise corrections of movement trajectories so as to ensure the endpoint accuracy of the movement (Adam, 1992; Milner & Ijaz, 1990; Rose & Christina, 2006). Therefore, the movement becomes more feedback dependent and slower. Additionally, correcting trajectories involves changing movement directions and resisting the inertial force being exerted on the hand (Milner & Ijaz, 1990). As an object becomes smaller, more movement corrections are needed. As a result, people tend to use a strategy of making a less forceful movement to decrease the inertial force and thus make movement corrections easier (Milner & Ijaz, 1990).

Effects of object distance in patients

A farther object induced slower, more feedback dependent, but more forceful movements in patients, which is consistent with the research findings in healthy adults (Adam, 1992; Fitts, 1954). Our study further found that a farther object elicited more direct movements and extends earlier findings by showing that the effects of object distance also exist in patients with schizophrenia. When people reach for a farther object, their hands need to generate a greater force at movement initiation to accelerate through a longer distance before arriving in the vicinity of the object (Elliott et al., 2001; Wu, Lin, Lin, Chang, & Chen, 2005). However, a more forceful hand movement also means a greater inertial force being exerted on the hand, which decreases the possibility of changing movement direction (Milner & Ijaz, 1990). Therefore, the hand tends to reach along a more direct path to grasp the object. Moreover, the larger inertial force on the hand also makes movement corrections more difficult (Milner & Ijaz, 1990). In order to complete the corrections and grasp the object successfully, the hand relies more on the assistance of proprioceptive and visual feedback, which leads to more feedback-dependent movements.

Strengths and clinical implications

The major contributions of this study are that (1) it identified specific impairments in reaching kinematics of patients with mild schizophrenia, and (2) it supported the use of object size and distance to change kinematic performance of reaching in patients. Our findings provide some clinical implications. First, movement training may focus on optimizing movement speed and spatial efficiency of reaching in patients. Second, occupational therapists may plan rehabilitation activities for patients according to impacts of object size and distance on reaching kinematics. If occupational therapy aims to remediate movement impairments, reaching tasks may be graded appropriately by gradually decreasing object size or increasing object distance to present bigger challenges to movement speed in patients. Conversely, a shorter object distance may be provided in reaching activities to gradually challenge patients' spatial efficiency. On the other hand, if occupational therapy approaches are to compensate for movement dysfunction, reaching tasks may be adapted accordingly to suit patients' remaining abilities. For example, a larger or closer object may be provided for patients to elicit faster reaching movements. A farther object makes it easier for patients to reach in a more direct way.

Limitations and future research

One limitation of this study is that our findings may not be generalizable to all patients with schizophrenia because we only enrolled patients with mild schizophrenia, who were defined as those without cognitive impairments and extrapyramidal motor symptoms. Future research may replicate this study to patients with different severities of motor or cognitive symptoms as well as to those taking different types of medications to confirm the effects of object size and distance. Future studies may also examine long-term effects of movement training that incorporates the manipulation of object size and distance in patients with schizophrenia.

Conclusions

Patients with mild schizophrenia had slower and less direct reaching movements than did healthy controls. A larger object induced faster, more preprogrammed, and more forceful movements in patients. A farther object induced slower, more feedback dependent, but more forceful and more direct movements. Our findings of kinematic deficiencies in patients suggest the need of movement training for this population. Moreover, the results concerning the effects of object size and distance on movement kinematics may help occupational therapists grade or adapt reaching activities in order to remediate or compensate for movement impairments in patients with mild schizophrenia.

Acknowledgments

We thank Ms Yen-Li Chao, Ms Pi-Jou Lin, and Mr Guang-Ze Pan for assisting with the data collection.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

References

Adam, J. J. (1992). The effects of objectives and constraints on motor control strategy in reciprocal aiming movements. *Journal of Motor Behavior*, 24, 173–185. doi:10.1080/00222895.1992.9941613

Alberts, J. L., Saling, M., Adler, C. H., & Stelmach, G. E. (2000). Disruptions in the reach-to-grasp actions of Parkinson's patients. *Experimental Brain Research*, 134, 353–362. doi:10.1007/s002210000468

American Occupational Therapy Association (2014). Occupational therapy practice framework: Domain and process (3rd ed.). *American Journal of Occupational Therapy*, 68, S1–S48. doi:10.5014/ajot.2014.682006

American Psychiatric Association (1994). *Diagnostic and statistical manual of mental disorders*. (4th ed.). Washington, DC: Author.

Arango, C., & Carpenter, W. T. (2011). The schizophrenia construct: Symptomatic presentation. In D. R. Weinberger & P. J. Harrison (Eds), *Schizophrenia* (3rd ed., pp. 9–23). West Sussex, UK: Wiley-Blackwell.

Canning, C. (2010). Parkinson's disease. In J. Carr & R. Shepherd (Eds), *Neurological rehabilitation: Optimizing motor performance* (2nd ed., pp. 307–334). Edinburgh, UK: Churchill Livingstone Elsevier.

Carnahan, H., Elliott, D., & Velamoor, V. R. (1996). Influence of object size on prehension in leukotomized and unleukotomized individuals with schizophrenia. *Journal of Clinical and Experimental Neuropsychology*, 18, 136–147. doi:10.1080/01688639608408269

Castiello, U., Bennett, K., Bonfiglioli, C., Lim, S., & Peppard, R. F. (1999). The reach-to-grasp movement in Parkinson's disease: Response to a simultaneous perturbation of object position and object size. *Experimental Brain Research*, 125, 453–462. doi:10.1007/s002210050703

Castiello, U., Stelmach, G. E., & Lieberman, A. N. (1993). Temporal dissociation of the prehension pattern in Parkinson's disease. *Neuropsychologia*, 31, 395–402. doi:10.1016/0028-3932(93)90162-s

Chatterjee, A., Chakos, M., Koreen, A., Geisler, S., Sheitman, B., Woerner, M., ... Lieberman, J. A. (1995). Prevalence and clinical correlates of extrapyramidal signs and spontaneous dyskinesia in never-medicated schizophrenic patients. *American Journal of Psychiatry*, 152, 1724–1729. doi:10.1176/ajp.152.12.1724

Cheng, J. J., Ho, H., Chang, C. J., Lan, S. Y., & Hwu, H. G. (1996). Positive and negative syndrome scale (PANSS): Establishment and reliability study of a Mandarin Chinese language version. *Chinese Psychiatry*, 10, 251–258.

Chouinard, G., & Margolese, H. C. (2005). Manual for the extrapyramidal symptom rating scale (ESRS). *Schizophrenia Research*, 76, 247–265. doi:10.1016/j.schres.2005.02.013

Chouinard, G., Ross-Chouinard, A., Annable, L., & Jones, B. (1980). The extrapyramidal symptom rating scale. *Canadian Journal of Neurological Sciences*, 7, 233–239.

Cohen, J. (1988). The analysis of variance. In J. Cohen (Ed.), *Statistical power analysis for the behavioral sciences* (2nd ed., pp. 273–406). Hillsdale, NJ: Lawrence Erlbaum.

Elliott, D., Helsen, W. F., & Chua, R. (2001). A century later: Woodworth's (1899) two-component model of goal-directed aiming. *Psychological Bulletin*, 127, 342–357. doi:10.1037//0033-2909.127.3.342

Fitts, P. M. (1954). The information capacity of the human motor system in controlling the amplitude of movement. *Journal of Experimental Psychology*, 47, 381–391. doi:10.1037/h0055392

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research*, 12, 189–198. doi:10.1016/0022-3956(75)90026-6

Guo, N. W., Liu, H. C., Wong, P. F., Liao, K. K., Yan, S. H., Lin, K. P., ... Hsu, T. C. (1988). Chinese version and norms of the mini-mental state examination. *Journal of Rehabilitation Medicine Association*, 16, 52–59.

Haddad, P. M., & Mattay, V. S. (2011). Neurological complications of antipsychotic drugs. In D. R. Weinberger & P. J. Harrison (Eds.), *Schizophrenia* (3rd ed., pp. 561–576). West Sussex, UK: Wiley-Blackwell.

Hofer, A., Kemmler, G., Eder, U., Edlinger, M., Hummer, M., & Fleischhacker, W. W. (2004). Quality of life in schizophrenia: *The impact of psychopathology, attitude toward medication, and side effects. Journal of Clinical Psychiatry*, 65, 932–939. doi:10.4088/JCP.v65n0709

Kamper, D. G., McKenna-Cole, A. N., Kahn, L. E., & Reinkensmeyer, D. J. (2002). Alterations in reaching after stroke and their relation to movement direction and impairment severity. *Archives of Physical Medicine & Rehabilitation*, 83, 702–707. doi:10.1053/apmr.2002.32446

Kao, Y. C., Liu, Y. P., Chou, M. K., & Cheng, T. H. (2011). Subjective quality of life in patients with chronic schizophrenia: Relationships between psychosocial and clinical characteristics. *Comprehensive Psychiatry*, 52, 171–180. doi:10.1016/j.comppsych.2010.05.008

Kay, S. R., Fiszbein, A., & Opler, L. A. (1987). The positive and negative syndrome scale (PANSS) for schizophrenia. *Schizophrenia Bulletin*, 13, 261–276. doi:10.1093/schbul/13.2.261

Kluzik, J., Fetters, L., & Coryell, J. (1990). Quantification of control: A preliminary study of effects of neurodevelopmental treatment on reaching in children with spastic cerebral palsy. *Physical Therapy*, 70, 65–76.

Lin, K. C., Chen, Y. A., Chen, C. L., Wu, C. Y., & Chang, Y. F. (2010). The effects of bilateral arm training on motor control and functional performance in chronic stroke: A randomized controlled study. *Neurorehabilitation and Neural Repair*, 24, 42–51. doi:10.1177/1545968309345268

Lin, K. C., Wu, C. Y., Wei, T. H., Lee, C. Y., & Liu, J. S. (2007). Effects of modified constraint-induced movement therapy on reach-to-grasp movements and functional performance after chronic stroke: A randomized controlled study. *Clinical Rehabilitation*, 21, 1075–1086. doi:10.1177/0269215507079843

MacKenzie, C. L., Marteniuk, R. G., Dugas, C., Liske, D., & Eickmeier, B. (1987). Three-dimensional movement trajectories in Fitts' task: Implications for control. *The Quarterly Journal of Experimental Psychology Section A*, 39, 629–647. doi:10.1080/14640748708401806

Milner, T. E., & Ijaz, M. M. (1990). The effect of accuracy constraints on three-dimensional movement kinematics. *Neuroscience*, 35, 365–374. doi:10.1016/0306-4522(90)90090-Q

Newell, K. M., & Valvano, J. (1998). Therapeutic intervention as a constraint in learning and relearning movement skills. *Scandinavian Journal of Occupational Therapy*, 5, 51–57. doi:10.3109/11038129809035730

Pappa, S., & Dazzan, P. (2009). Spontaneous movement disorders in antipsychotic-naive patients with first-episode psychoses: A systematic review. *Psychological Medicine*, 39, 1065–1076. doi:10.1017/s0033291708004716

Platz, T., Prass, K., Denzler, P., Bock, S., & Mauritz, K. H. (1999). Testing a motor performance series and a kinematic motion analysis as measures of performance in high-functioning stroke patients: Reliability, validity, and responsiveness to therapeutic intervention. *Archives of Physical Medicine and Rehabilitation*, 80, 270–277. doi:10.1016/s0003-9993(99)90137-5

Rogers, D. (1992). Schizophrenia. In D. Rogers (Ed.), *Motor disorder in psychiatry: Towards a neurological approach* (pp. 27–39). Chichester, UK: John Wiley & Sons.

Rose, D. J., & Christina, R. W. (2006). Visual and vestibular system contributions to action. In D. J. Rose & R. W. Christina (Eds), *A multilevel approach to the study of motor control and learning* (2nd ed., pp. 93–126). San Francisco, CA: Pearson/Benjamin Cummings.

Shenton, M. E., Dickey, C. C., Frumin, M., & McCarley, R. W. (2001). A review of MRI findings in schizophrenia. *Schizophrenia Research*, 49, 1–52. doi:10.1016/S0920-9964(01)00163-3

Torrey, E. F. (2002). Studies of individuals with schizophrenia never treated with antipsychotic medications: A review. *Schizophrenia Research*, 58, 101–115. doi:10.1016/S0920-9964(02)00381-X

Wang, C. Y., Hwang, W. J., Fang, J. J., Sheu, C. F., Leong, I. F., & Ma, H. I. (2011). Comparison of virtual reality versus physical reality on movement characteristics of persons with Parkinson's disease: Effects of moving targets. *Archives of Physical Medicine and Rehabilitation*, 92, 1238–1245. doi:10.1016/j.apmr.2011.03.014

Wang, S. M., Kuo, L. C., Ouyang, W. C., Hsu, H. M., Lin, K. C., & Ma, H. I. (2014). Effects of object size on unimanual and bimanual movements in patients with schizophrenia. *American Journal of Occupational Therapy*, 68, 230–238. doi:10.5014/ajot.2014.009811

Wu, C. Y., Chen, C. L., Tang, S. F., Lin, K. C., & Huang, Y. Y. (2007). Kinematic and clinical analyses of upper-extremity movements after constraint-induced movement therapy in patients with stroke: A randomized controlled trial. *Archives of Physical Medicine & Rehabilitation*, 88, 964–970. doi:10.1016/j.apmr.2007.05.012

Wu, C. Y., Chuang, L. L., Lin, K. C., Chen, H. C., & Tsay, P. K. (2011). Randomized trial of distributed constraint-induced therapy versus bilateral arm training for the rehabilitation of upper-limb motor control and function after stroke. *Neurorehabilitation and Neural Repair*, 25, 130–139. doi:10.1177/1545968310380686

Wu, C. Y., Lin, K. C., Lin, K. H., Chang, C. W., & Chen, C. L. (2005). Effects of task constraints on reaching kinematics by healthy adults. *Perceptual and Motor Skills*, 100, 983–994. doi:10.2466/pms.100.3.983-994

Wu, C. Y., Wong, M. K., Lin, K. C., & Chen, H. C. (2001). Effects of task goal and personal preference on seated reaching kinematics after stroke. *Stroke*, 32, 70–76. doi:10.1161/01.STR.32.1.70