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Original Article

A self-administered immersive virtual reality tool for assessing cognitive impairment in patients with cancer

Yingchun Zeng [a], Qiongyao Guan [b], Yan Su [b], Qiubo Huang [c], Jun Zhao [d], Minghui Wu [d], Qiaohong Guo [e], Qiyuan Lyu [f,*], Yiyu Zhuang [g,*], Andy SK Cheng [h]

[a] School of Medicine, Hangzhou City University, Hangzhou, China
[b] Department of Nursing, The Third Affiliated Hospital of Kunming Medical University/Yunnan Cancer Hospital, Kunming, China
[c] Department of Thoracic Surgery I, The Third Affiliated Hospital of Kunming Medical University/Yunnan Cancer Hospital, Yunnan Cancer Center, The International Cooperation Key Laboratory of Regional Tumor in High Altitude Area, Kunming, China
[d] School of Computer and Computing Science, Hangzhou City University, Hangzhou, China
[e] School of Nursing, Capital Medical University, Beijing, China
[f] School of Nursing, Jinan University, Guangzhou, China
[g] Department of Nursing, Sir Run Run Shaw Hospital, Zhejiang University School of Medicine, Hangzhou, China
[h] Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, Hong Kong SAR, China

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ABSTRACT

Objective: This study was aimed at exploring the feasibility and validity of a self-administered immersive virtual reality (VR) tool designed to assess cognitive impairment in patients with cancer.
Methods: In a cross-sectional survey study, an immersive tool was used to rate the previously recommended core assessment domains of cancer-related cognitive impairment—comprising attention, verbal learning memory, processing speed, executive function and verbal fluency—via an interactive VR scenario.
Results: A total of 165 patients with cancer participated in this study. The participants' mean age was 47.74 years (SD = 10.59). Common cancer types included lung, liver, breast and colorectal cancer, and most patients were in early disease stages (n = 146, 88.5%). Participants' performance in the VR cognition assessment showed a moderate to strong positive correlation with their paper-and-pencil neurocognitive test results (r = 0.34–0.76, P < 0.001), thus indicating high concurrent validity of the immersive VR cognition assessment tool. For all participants, the mean score for the VR-based cognition assessment was 5.41 (SD = 0.70) out of a potential maximum of 7.0. The mean simulation sickness score for the VR-based tool, as rated by the patients, was 0.35 (SD = 0.19), thereby indicating that minimal simulation sickness occurred during the VR-assisted cognition assessment.
Conclusions: Given its demonstrated validity, and the patients' high presence scores and minimal sickness scores, this VR-based cognition assessment tool is a feasible and acceptable instrument for measuring cognitive impairment in patients with cancer. However, further psychometric assessments should be implemented in clinical settings.

Introduction

Cancer, the most common malignancy, is a leading cause of death worldwide.[1] More than one-quarter of all cancer cases globally occur in China.[2] However, with advances in medical technologies and treatment, the 5-year survival rate for patients with cancer is approximately 67%.[1] The increase in the number of cancer survivors has led considerable attention to be paid to cancer survivorship issues.[1] In particular, cancer-related cognitive impairment is one of the most common sequelae in cancer survivors, and the prevalence of cancer-related cognitive impairment in patients with cancer has been estimated to be as high as 75%.[3]

Cancer-related cognitive impairment may significantly affect the ability of patients with cancer to perform activities of daily living and maintain their independence,[4,5] thus imposing psychological distress and decreasing quality of life. Hence, the ability to accurately evaluate cognitive function in patients with cancer may be critical for the early detection of cancer-related cognitive impairment; moreover, reliable test

* Corresponding author.
E-mail addresses: yuanqlv@163.com (Q. Lyu), 596830447@qq.com (Y. Zhuang).

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results could help healthcare providers develop and optimize interventions to improve cognitive function in these patients.[5]

The commonly used subjective scales for assessing cancer-related cognitive impairment are the functional assessment of cancer therapy—cognitive function and the multiple ability self-report questionnaire. The most common objective cognitive tests include the Rey auditory verbal learning test, Hopkins verbal learning test—revised, trial making test, digit symbol and digit span.[6] Because the objective cognitive tests were developed for all populations, they may be unable to detect the subtle cognitive changes that occur in cancer-related cognitive impairment.[5] In addition, neurocognitive tests are typically administered in controlled environments and therefore may lack ecological validity in directly measuring real-life cognitive functioning.[7] Owing to the low ecological validity of these existing cognitive scales and neurocognitive tests, novel cognitive tools to assess real-world functioning in patients with cancer are urgently needed.[7]

Virtual reality (VR) technology offers a suitable assessment modality for measuring real-world cognitive functioning, and provides simulated naturalistic and engaging cognitive challenges in a controlled virtual environment.[7,8] Although an immersive VR tool was previously developed for assessing cognitive function among patients with mood and psychological disorders,[8] this tool may have deficiencies in certain areas that are critical for assessing cognitive function in patients with cancer. According to the International Cognition and Cancer Task Force, cancer-related cognitive impairment assessment should include the core cognitive domains of attention, verbal learning memory, processing speed, executive function and verbal fluency.[9] Hence, a VR tool designed to measure real-world cognitive function in patients with cancer should incorporate these core cognitive domains.

Accordingly, the aim of this study was to explore the feasibility and validity of a self-administered immersive VR tool designed to assess cognitive impairment in patients with cancer.

Methods

Study design

This cross-sectional study examined the feasibility and validity of a novel VR cognition assessment tool tailored to cancer survivors.

Study participants

All participants were recruited at the Cancer Centre of Southern Medical University. The eligibility criteria were adults 18–65 years of age who had completed primary cancer treatment. The exclusion criterion was participants' reporting severe visual difficulties, such as cataract symptoms, while performing the VR cognition assessment.

VR cognition assessment

The details of development of the VR cognitive assessment tool can be found in our previous report.[10] Three virtual environments were created for assessing the key cognitive domains of cancer-related cognitive impairment, according to the suggestions of the International Cognition and Cancer Task Force. Specifically, a virtual shopping mall was created to assess verbal learning and memory, a virtual supermarket was designed to assess verbal fluency, and a virtual outdoor scenario was constructed to assess information processing speed and executive function. Fig. 1 illustrates the VR cognition assessment tool. Study participants wore PICO neo-3 portable VR headsets (https://www.picoxr.com/). In addition, the participants used a hand-held controller while self-administering the test with the VR cognitive assessment tool, and navigated through the environment by conducting virtual tasks while following the instructions of a pre-recorded voice. This study operationally defined "a self-administered tool" as an automatic data-collection tool, such that the researcher is entirely absent when research participants completed the full cognitive assessment, navigating according to the instructions of the VR headset.

Standard neurocognitive tests

The selected neurocognitive functional assessments for patients with cancer were those recommended by the International Cognition and Cancer Task Force, including the Chinese version of the auditory verbal learning test—revised version,[11] the Chinese version of the trial making test and the Chinese version of the controlled oral word association test.[12] Our previous study has provided detailed descriptions of the use of these three paper-and-pencil neurocognitive tests.[13] A summary of VR cognition assessment and associated neurocognitive tests is shown in Table 1.

Assessment of patient experience in using the VR

A two-item questionnaire was developed to assess the patients' overall experience of simulation sickness during the VR cognitive assessment, and the level of presence attainable in the VR scenario, in terms of the

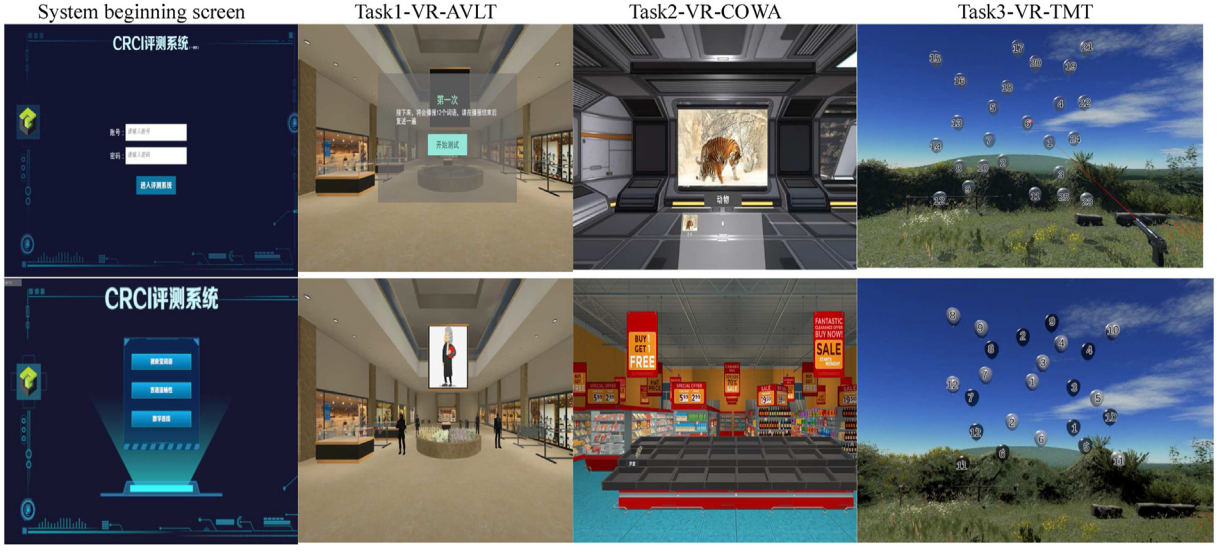

Fig. 1. Scenarios of VR cognition assessment. System beginning screen-up: need to input each assessor's account name and code, then the down screening is show three assessing VR tasks. Cancer survivors complete the following tasks in a virtual environment: A: Task 1 (VR-verbal memory); B: Task 2 (VR-verbal fluency); Task 3-up (VR-information processing speed); Task3-down (VR-executive function). VR, virtual reality.

Table 1
Summary of VR cognition assessment and associated neurocognitive tests.

Cognitive domains	VR cognition assessment	Neurocognitive tests
Verbal Learning and Memory	Number of correctly remembered goods in the shopping mall	AVLT
Information Processing speed	Using virtual gun to connect numbers in a sequence	TMT-A
Executive function	Using virtual gun to connect white and black color numbers in a sequence	TMT-B
Verbal fluency	Number of correctly recognized fruits, vegetables and name of animals within a minute separately in a supermarket	COWA

AVLT, auditory-verbal learning test; COWA, controlled oral word association test; TMT, trail making test; VR, virtual reality.

patients' involvement in, the naturalness of, and the interface quality of, the VR environment during the cognitive assessment.[14] Eight-point scales were used for both items. Thus, for simulation sickness, the scores ranged from 0 (none) to 7 (severe); similarly, the scores for presence ranged from 0 (no presence) to 7 (high presence).

Data collection

Data were collected from November 2021 to March 2022 at a cancer centre in southern China. Before data collection, all research participants provided written informed consent and were informed of their option to withdraw from the study at any time without penalty. The VR cognitive assessment was self-administered by each patient, according to instructions provided by a pre-recorded voice in conjunction with a text display. The paper-and-pencil neurocognitive tests were administered by a trained research nurse. All cancer survivors performed the VR cognitive measures and traditional neurocognitive tests on the same day.

Data analysis

Statistical analyses were conducted in SPSS version 25 (IBM Corporation, Armonk, New York, USA). Descriptive statistics and correlation analysis were used to describe the characteristics of the study participants and to identify the correlations between the VR cognitive measures and the standard neurocognitive tests. An alpha level of $P < 0.05$ (two-tailed) was defined as the threshold for statistical significance.

Ethical considerations

The study obtained ethical approval from the Human Ethics Committee of the Cancer Centre of Southern Medical University (IRB No. 202111-K2). All research participants provided written consent forms and voluntarily participated in this study.

Results

Sociodemographic and clinical characteristics

The sociodemographic characteristics and clinical variables are displayed in Table 2. A total of 165 patients who had completed primary cancer treatment participated in this study. The participants' ages ranged from 20 to 65 years, and the mean age was 47.74 years (SD = 10.59). Almost all participants were married ($n = 154$, 93.3%). Common cancer types were lung ($n = 51$, 30.9%), liver ($n = 31$, 18.8%), breast ($n = 18$, 10.9%) and colorectal ($n = 12$, 7.3%). Most patients were in early stages of disease ($n = 146$, 88.5%).

Concurrent validity of the VR cognitive assessment tool

The means of the scores from the VR cognitive assessment and the neurocognitive tests are presented in Table 3. The participants' performance on the VR cognition assessment showed a moderate to strong positive correlation with the paper-and-pencil neurocognitive test results ($r = 0.34–0.76$, $P < 0.001$; Table 4), thus indicating high concurrent validity of this immersive VR cognitive assessment tool.

Table 2
Demographic characteristics of cancer survivors ($n = 165$).

Variables	*n* (%)	Mean (SD) (range)
Age, years (range)		47.74 (10.59) (20–65)
Gender, male	82 (49.7)	
Highest education		
Primary school or below	104 (63.0)	
High school	44 (26.7)	
College or above	17 (10.3)	
Marital status		
Married	154 (93.3)	
Single/divorced	11 (6.7)	
Employment status		
Employed	35 (21.2)	
Unemployed/retired	130 (78.8)	
Diagnosis		
Lung cancer	51 (30.9)	
Breast cancer	31 (18.8)	
Liver cancer	18 (10.9)	
Colorectal cancer	12 (7.3)	
Other (< 10 cases per category)	53 (32.1)	
Disease stage, early	146 (88.5)	
Treatment type		
Surgery only	27 (16.4)	
Radiation therapy only	10 (6.1)	
Surgery + chemotherapy	39 (23.6)	
Surgery + radiation therapy	21 (12.7)	
Surgery + chemo + radiation therapy	68 (41.2)	

Usability and acceptability of the VR cognitive assessment

As shown in Table 3, the mean score for the perception of presence in the VR cognition assessment was 5.41 (SD = 0.70), thus indicating a high level of presence with respect to the maximum possible score of 7.0. In contrast, the mean simulation sickness score for the VR cognitive assessment was 0.35 (SD = 0.19), thus indicating that the patients experienced minimal simulation sickness.

Table 3
Mean of VR cognition and neurocognitive tests scores and VR feedback scores.

	Mean (SD)	
	VR-cognition assessment	Neurocognitive tests
Verbal learning, immediate and delayed memory		
1st immediate recall (0–12)	5.15 (3.16)	4.30 (2.01)
2nd immediate recall (0–12)	6.99 (2.78)	7.11 (2.01)
3rd immediate recall (0–12)	9.01 (3.24)	8.89 (2.02)
5-min delayed recall (0–12)	7.98 (3.13)	8.26 (2.14)
20-min delayed recall (0–12)	7.64 (2.15)	8.18 (2.28)
Categorization (0–12)	9.14 (2.73)	9.47 (2.33)
Recognition (0–24)	20.21 (5.16)	21.01 (1.30)
Information processing speed (s)	72.01 (41.93)	51.46 (20.18)
Executive function (s)	80.17 (41.33)	61.24 (26.55)
Global verbal fluence	27.29 (9.97)	33.81 (7.34)
Presence in the VR environment (0–7)	5.41 (0.70)	
VR simulation sickness (0–7)	0.35 (0.19)	

Responses for processing speed and executive function, less time (unit is seconds) indicating being function; Response for verbal fluence, high scores indicating better functioning; Response for presence and simulation sickness in the VR environment were rated from 0 (none) to 7 (high degree).

Table 4
Correlations of VR cognition measures with standardized neurocognitive tests.

Pearson's r	AVLT1	AVLT2	AVLT3	AVLT4	AVLT5	AVLT6	AVLT7	TMT-A	TMT-B	COWA
VR-AVLT1	0.58**									
VR-AVLT2		0.70**								
VR-AVLT3			0.72**							
VR-AVLT4				0.67**						
VR-AVLT5					0.55**					
VR-AVLT6						0.64**				
VR-AVLT7							0.76**			
VR-TMT-A								0.52**		
VR-TMT-B									0.34**	
VR-COWA										0.45**

AVLT, auditory-verbal learning test; COWA, controlled oral word association test; TMT, trail making test; VR, virtual reality.
**$P < 0.001$.

Discussion

Summary of key findings

This study assessed an innovative new cognitive assessment tool for patients with cancer that uses immersive VR technology. The self-administered immersive VR assessment evaluated herein is a comprehensive multidomain tool for cognitive examination of the domains of cancer-related cognitive impairment, including attention, verbal and learning memory, executive functioning, and information processing speed, as suggested by the International Cancer and Cognition Task Force.[9] According to the study findings, the tool's high mean presence score indicated the acceptable ecological validity of this tool. As an additional positive outcome, the study participants reported neither discomfort nor any adverse events during the VR cognitive assessment.

Acceptability and validity of VR cognitive assessment

Acceptability and ecological validity

According to the literature, a tool based on VR technology with enhanced ecological validity may improve cognitive assessment in real-world settings,[15,16] by providing a vivid, attractive experience that allows individuals to hear and feel simulated environments and interact with a simulated virtual environment in real time.[17] In addition, VR can accurately record real-time data without requiring researchers' subjective assessment and note-taking.[10] Hence, VR is emerging as a valuable tool that nurses can use to conduct cognitive assessments. Perhaps more importantly, this self-administered VR cognitive assessment provides a level of automation that decreases the time commitment of a certified neuropsychologist, because other healthcare staff can oversee the test.

Concurrent validity of VR cognitive assessment

This study identified a statistically significant correlation between the findings of the immersive VR cognitive assessment and traditional paper-and-pencil neurocognitive tests, thus indicating the good concurrent validity of this innovative new VR instrument for patients with cancer. In clinical nursing practice, this self-administered VR cognitive assessment can help nurses evaluate cognitive function in patients with cancer in real-world situations. As with previous VR cognitive tools,[7,8] the tool examined herein resembles classical neurocognitive tests while being embedded in a real-world shopping mall scenario, thus demonstrating efficacy in terms of both cognition and functioning.[7]

Limitations

Although the current investigation evaluated the first self-administered immersive VR tool developed to assess cognition in cancer, this study has several limitations. For example, the current study was conducted at a single medical centre in southern China, thereby limiting the generalizability of the study findings. Therefore, future research should include multicentre studies. In addition, most research participants were in early stages of illness; thus, future research should expand the results by recruiting a sample with a well-balanced disease stage ratio. Finally, this study did not include an age-matched healthy control group and consequently cannot provide a cut-off value for distinguishing patients with cancer with versus without cognitive impairment.

Implications in nursing

According to the study findings, this self-administered immersive VR tool is an ecologically valid instrument for assessing cognition in patients with cancer. Notably, accurate evaluation of cognitive impairment in patients with cancer is essential for facilitating the development of effective interventions, because oncology nurses are uniquely positioned to detect and manage cancer-related sequelae, such as cognitive impairment.[18] In light of nurses' key roles in applying advanced technologies in every facet of nursing care, VR-based methods offer promising solutions in the nursing field.[10] Therefore, educating nurses on how to incorporate VR technologies into nursing has the potential to transform and advance healthcare.[10]

Conclusions

Given that this VR cognitive assessment tool received high scores regarding users' sense of presence without provoking sickness, it can be considered an acceptable and ecologically valid instrument for cognitive assessment in patients with cancer. The results of this immersive VR-based tool were strongly correlated with those of traditional neurocognitive tests, thus indicating that this VR cognitive tool has theoretical underpins in neurocognitive assessment. Other types of construct validity should be established before this tool is considered valid for assessing neurocognitive performance and daily functioning in patients with cancer.

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CRediT author statement

Yingchun Zeng: Conceptualization, Formal analysis, Writing—Original Draft. **Qiongyao Guan, Yan Su, Qiubo Huang**: Methodology, Writing—Review & Editing. **Minghui Wu and Qiaohong Guo**: Investigation, Formal analysis. **Qiyuan Lyu, Bin Zhu**: Conceptualization, Investigation. **Qiyuan Lyu, Yiyu Zhuang**: Conceptualization, Investigation, Writing—Review & Editing. All authors had full access to all data in the study, and the corresponding author had final responsibility for the decision to submit for publication. The corresponding authors attest that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted.

Declaration of competing interest

The authors declare no conflict of interest. The first author, Dr. Yingchun Zeng, is an editorial board member of Asia-Pacific Journal of Oncology Nursing. The article was subject to the journal's standard procedures, with peer review handled independently of Dr. Zeng and their research groups.

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Ethics statement

The study obtained ethical approval from the Human Ethics Committee of the Cancer Centre of Southern Medical University (IRB No. N202111-K2). All participants provided written informed consent to participate.

Data availability statement

Data will be provided by the first author on reasonable request by email: chloezengyc@hotmail.co.uk.

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