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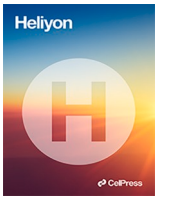

Research article

Distorted time perception in patients with neurocognitive impairment

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ABSTRACT

Background: Time perception is known to be distorted in patients with neuropsychiatric disorders. Therefore, this study aims to investigate the correlation between cognitive decline and time distortion by examining time perception in participants with neurocognitive impairment (Alzheimer's disease [AD], vascular dementia [VD], and Parkinson's disease dementia [PDD]) compared to those with subjective cognitive impairment (SCI).

Methods: Overall, 569 participants with cognitive decline complaints between 2013 and 2022 were investigated. Participants were subjected to a verbal estimation task, time production task, time comparison task, and neuropsychological assessments.

Results: Time perception abilities were distorted in patients with neurocognitive impairment compared to those with SCI. Despite similar educational backgrounds, the vascular cognitive impairment (VCI)/VD group demonstrated the lowest MMSE scores (22.4 ± 4.2, p-value <0.001) and larger time-estimation errors. Patients with VCI/VD significantly underestimated time in the 35-s (19.6 ± 12.6s) and 60-s (28.7 ± 19.9s) tasks. In the time production task, patients with VCI/VD produced shorter times in their 15-s (12.7 ± 4.3; p-value = 0.001), 30-s (23.6 ± 8.3; p value < 0.001), and 60-s (43.8 ± 18.9; p-value <0.001) trials. In the time comparison task, the VCI/VD group had significantly fewer correct answers than that in the SCI groups (6.0 ± 1.3 vs. 7.1 ± 0.9, p-value <0.001). Correlation analysis revealed that multiple cognitive functions are involved in the time perception tasks.

Conclusions: Patients with VCI/VD had the poorest time perception. These findings may provide a modest contribution to understanding the underlying pathophysiology and psychological connections related to temporal abilities in time perception.

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1. Introduction

Time perception is essential for planning and goal-setting, decision-making, emotional regulation, and memory [1]. Pathophysiological abnormalities in human timing and time perception captivate fundamental and clinical researchers for various reasons [2]. Basic researchers seek to understand the psychological processes underlying normal timing. Clinically, examining timing skills in individuals with specific psychiatric or cognitive disorders can improve our understanding of how to address these issues medically. Subjective time perception is complex and multifaceted, influenced by factors including age, sex, emotions, and neurological or psychiatric disorders [3]. Recently, rapid growth in academic research has been observed regarding neural timing using diverse methodological approaches [4]. Patients with neurological and psychiatric disorders, including Parkinson's disease [5], depression [6], schizophrenia [7], Korsakoff's syndrome [8], and brain injury [9] exhibit distortions in time perception [10]. Studies on patients with Parkinson's disease (PD) have identified the basal ganglia as a key component of motor and perceptual timing [5]. Patients with PD perceived 1 s intervals as longer than the actual 1 s. The extent of this distortion in time perception correlates with the severity of their PD symptoms [2,11]. In schizophrenia, patients generally experience a reduced clock speed, leading those on antipsychotic medication to have increased difficulty in timing visual signals [2].

Furthermore, experimental studies suggest that multiple brain regions, including the cerebral cortex, basal ganglia (BG), and cerebellum, may be involved in temporal time processing [1]. The frontal cortex is known to be associated with processing temporal information in short- and long-term memory [12]. The BG facilitates motor control execution [12]. BG integrity is essential for the production and reproduction of short time intervals [12]. The parietal cortex is crucial for the perception of external stimuli, and the cerebellum is connected to all parts of the central nervous system [12]. The lateral cerebellum is involved in time synchronization, while the BG is related to time acceleration [12]. Therefore, it was hypothesized that time perception would be worse in all patients with degenerative disease than those with subjective cognitive impairment (SCI), with a particularly significant decline in the vascular cognitive impairment (VCI)/vascular dementia (VD) group owing to structural brain damage. Despite the abundance of excellent studies, few have examined clinical symptoms and neuropsychological tests from the perspective of the neurologist. Therefore, this study aims to investigate the temporal ability of time perception by considering clinical symptoms and neuropsychological tests in patients with neurocognitive impairment compared to those with SCI. Moreover, in this study, the tests of time perception associated with more specific cognitive functions (such as frontal/executive, memory, and visuoperceptual.) were investigated by assessing the relationship between specific time perception performance and neuropsychological tests.

2. Material and methods

2.1. Study population

The study population consisted of patients who visited Kangdong Sacred Heart Hospital with complaints of cognitive decline

Table 1
Neurophychological test results according to the disease subtypes.

Disease types	Total	MCI/AD	VCI/VD	PDD	SCI	*p*-test
n	569	360	73	30	60	
Age	72.2 ± 8.9	73.0 ± 8.9	73.4 ± 7.5	74.5 ± 6.3	69.9 ± 8.2	**0.018**
Sex (%), Female	321 (56.4)	221 (61.4)	34 (46.6)	9 (30.0)	38 (63.3)	**0.001**
Handness, Right (%)	535 (93.7)	340 (94.4)	68 (93.2)	29 (96.7)	56 (93.3)	0.914
Left (%)	10 (1.8)	7 (1.9)	1 (1.4)	0 (0)	1 (1.7)	
Both (%)	16 (2.8)	9 (2.5)	3 (4.1)	1 (3.3)	3 (5.0)	
Education Year	9.1 ± 5.0	9.2 ± 5.1	8.7 ± 4.7	9.7 ± 5.4	8.1 ± 5.1	0.291
K MMSE total score	24.2 ± 3.8	24.1 ± 3.5	22.4 ± 4.2	23.0 ± 4.0	27.6 ± 2.0	**<0.001**
Digit span Forward	5.7 ± 1.3	5.7 ± 1.3	5.4 ± 1.4	5.7 ± 1.2	6.3 ± 1.5	**0.006**
Digit span Backward	3.4 ± 1.1	3.4 ± 1.0	2.8 ± 1.0	2.9 ± 1.0	3.9 ± 1.2	**<0.001**
Naming K BNT	40.0 ± 10.7	39.1 ± 10.2	36.3 ± 12.0	40.2 ± 9.0	47.7 ± 7.8	**<0.001**
Rey CFT copy score	29.4 ± 6.3	29.5 ± 5.8	25.8 ± 7.8	26.8 ± 8.9	33.2 ± 2.3	**<0.001**
RCFT immediate recall	14.8 ± 4.6	8.0 ± 6.2	7.6 ± 6.0	7.2 ± 4.8	15.4 ± 5.5	**<0.001**
RCFT delayed recall	2.9 ± 2.8	7.1 ± 6.3	6.8 ± 6.7	6.2 ± 4.8	14.8 ± 5.5	**<0.001**
RCFT recognition score	18.2 ± 2.9	17.1 ± 2.6	17.5 ± 2.7	17.3 ± 2.4	19.4 ± 1.9	**<0.001**
SVLT recall total score	8.8 ± 6.5	14.6 ± 4.2	12.7 ± 4.8	13.3 ± 5.1	19.1 ± 3.3	**<0.001**
SVLT Delayed recall total score	8.0 ± 6.7	2.4 ± 2.5	2.1 ± 2.4	2.4 ± 2.5	6.2 ± 1.7	**<0.001**
SVLT recognition score	17.4 ± 2.6	17.9 ± 2.8	18.0 ± 2.7	17.3 ± 2.6	20.8 ± 1.9	**<0.001**
COWAT animal	12.1 ± 4.4	12.0 ± 4.2	9.8 ± 3.8	11.7 ± 4.2	15.6 ± 3.5	**<0.001**
COWAT supermarket	12.1 ± 5.9	12.1 ± 5.3	8.7 ± 4.6	10.3 ± 6.0	17.4 ± 5.8	**<0.001**
COWAT phonemic total score	19.5 ± 10.3	19.9 ± 10.0	13.5 ± 9.5	17.3 ± 9.6	24.8 ± 9.0	**<0.001**
StroopTest Wordreading correct	107.2 ± 14.0	109.1 ± 8.3	98.2 ± 25.0	103.1 ± 15.5	110.6 ± 6.1	**<0.001**
StroopTest Colorreading correct	63.6 ± 27.4	64.4 ± 25.1	46.7 ± 28.3	47.7 ± 24.5	84.8 ± 20.5	**<0.001**

The Kruskal-Wallis analysis was conducted to analyze the differences and interactions between groups.
Abbreviations: MCI = mild cognitive impairment, AD = Alzheimer's disease, VCI = vascular cognitive impairment, VD = vascular dementia, PDD= Parkinson's disease dementia, SCI = subjective cognitive impairment, MMSE = Mini Mental State Examination, BNT= Boston Naming Test, RCFT = Rey complex figure test, SVLT= Seoul Verbal Learning Test, COWAT= Controlled Oral Word Association Test.

between September 2013 and January 2022 (Table 1). During the application of the Seoul Neuropsychological Screening Battery (SNSB), three validated time perception tasks were performed on all patients.

The reference group (subjective cognitive impairment group [SCI]) consisted of individuals who underwent cognitive function tests but did not meet the criteria for cognitive impairment (Mini-Mental State Examination [MMSE] z-score >1.0 SD). Alzheimer's disease (AD) was defined based on the National Institute of Neurological and Communicative Disorders and Strokes-Alzheimer's Disease and Related Disorders Association (NINCDS-ADRDA) criteria for probable AD [13]. Vascular dementia (VD) was defined according to the NINDS-AIREN criteria [14]. VD and vascular cognitive impairment were defined as follows: i) the presence of a cognitive disorder and ii) vascular disease as the predominant, if not exclusive, pathology contributing to the cognitive deficits [15]. Supplementary Table 1 shows the baseline characteristics for the VD or VCI. Parkinson's disease dementia (PDD) is characterized by a decline in thinking and reasoning skills that occurs in patients with Parkinson's disease, based on previous criteria [16]. Diagnosing idiopathic PD before dementia symptoms develop is the crucial initial step. A dementia diagnosis requires observing impairments in at least two of the four core cognitive areas (attention, memory, executive function, and visuospatial abilities) during clinical and cognitive assessments, with a severity that influences daily functioning [16]. Supplementary Table 2 shows the baseline characteristics for the PDD. Overall, 569 participants were included in this study. For the neuropsychological tests, each score was transformed into z-scores, and a mean z-score was calculated for each cognitive domain (attention, language, memory, visuospatial, and frontal/executive). The primary criterion for impaired function is defined as a mean z-score ≤ -1.0 SD.

Because this study is retrospective in nature and does not involve administering interventions to patients and with no exposure of patients' personal information, the necessity for patient consent is not considered. However, ethical clearance was obtained from the Institutional Review Board of Kangdong Sacred Heart Hospital approved the study protocol (IRB No. 2020-10-011), confirming the absence of ethical concerns.

2.2. Time perception evaluation

According to previous clinical reports, three tasks associated with time perception were conducted: a verbal estimation task, time production task, and time comparison task [8,17,18]. During these tasks, participants were seated approximately 60 cm in front of a 15-inch PC monitor screen. Commercial equipment was not used; instead, the inspection was conducted using PowerPoint with time settings. The verbal estimation task required participants to estimate the length of a presented interval in temporal units. Participants were asked to verbally estimate the length of time they believed a trial lasted while using verbal estimation methods. Random digits from 1 to 9 were displayed in a non-sequential order on a computer screen, and participants had to read them aloud. There experimental task included five time intervals (5, 10, 15, 35, and 60 s) (Supplemental Table 3) [18].

In the time production task, participants were instructed to reproduce a specified time interval in temporal units as instructed by the experimenter [18]. Participants used the index finger of their dominant hand to press the space bar on a computer keyboard. The start and end of each interval were marked by tapping the finger. The task included four time intervals (5, 15, 30, and 60 s) [17].

In the time comparison task, participants had to determine whether the second interval was longer or shorter than the first by comparing their durations [17]. The task consisted of eight trials: (3 s vs. 2 s; 3 s vs. 5 s; 3 s vs. 2.5 s; 3 s vs. 3.25 s; 5 s vs. 7 s; 12 s vs. 10 s; 25 s vs. 23 s; and 40 s vs. 45 s). The number of correct answers out of the eight trials was recorded. Each participant completed two practice trials to ensure they understood the task requirements.

2.3. Neuropsychological tests

Neuropsychological tests were performed using the Seoul Neuropsychological Screening Battery (SNSB) for all patients. The SNSB, first standardized in 2003, has been recognized as a primary comprehensive neuropsychological assessment tool in Korea. Moreover, it was initially adopted by the Clinical Research Center for Dementia in South Korea—a prominent multi-center cohort study launched in 2005. Since then, the SNSB has become a well-established and widely utilized dementia assessment tool in Korea [19].

This battery includes various quantitative tests: digit span, the Korean version of the Boston Naming Test (K-BNT), the Seoul Verbal Learning Test (SVLT) consisting of three learning-free recall trials of 12 words, a 20-min delayed recall trial for these 12 items, and a recognition test; the Rey–Osterrieth Complex Figure Test (RCFT) was used to assess copying, immediate and 20-min delayed recall, and recognition; the semantic and phonemic Controlled Oral Word Association Test (COWAT) was used to evaluate verbal fluency; and the Stroop Test was employed to measure attention, processing speed, and cognitive flexibility through word and color reading of 112 items over 2 min. Raw scores from these tests were converted to standardized scores (z-scores) based on the means of normal data from 1100 individuals (http://www.human-brainkorea.com/Item/Default.aspx?sub=SNSB_2). These scores were adjusted for age and educational level, enabling comparisons of performance across different patients.

2.4. Statistical analyses

Continuous variables were presented as the mean ± standard deviation (SD), while discrete variables were presented as number (percentage). Normal distribution was assessed for statistical analysis. Owing to the non-normal distribution of the data, differences among groups were analyzed using Kruskal–Wallis analysis. In the Verbal estimation task, the dependent variable is the numerical time duration for the exposed duration. In the time production task, the dependent variable is the duration indicated by the sentence that appeared at the center of the computer screen (e.g., "produce 5 s"). For the time comparison task, the dependent variable is the number of correct answers out of eight trials. Linear regression analysis was employed to analyze the association between time perception and

neuropsychological tests (RCFT copy, SVLT immediate recall and delayed recall, COWAT animal and phonemic, and Stroop for color reading). For descriptive statistics, χ2-tests or t-tests were performed, as appropriate. Analyses were conducted using SPSS Statistics 25.0 (IBM, Armonk, NY, USA) with an alpha level of 0.05.

2.5. Data availability statement

All data generated or analyzed during this study are included in this published article. Anonymized data will be shared upon reasonable request from any qualified investigator.

3. Results

Among the 569 participants enrolled in this study, 56.2 % (n = 321) were women. The mean age of all participants was 72.2 ± 8.9 years, while the mean education year was 9.1 ± 5.0 years. Table 1 shows the baseline demographic and clinical characteristics**.** In the verbal estimation and time production tests, participants perceived 5 s (a relatively short duration) to be longer than 5 s (5.5 ± 2.5 s), while they evaluated other time durations to be shorter than their actual times (10 s; 7.5 ± 3.2, 15 s; 11.2 ± 6.8, 35 s; 23.5 ± 13.5, 60 s; 39.3 ± 28.1). In the time production test, participants estimated a mean time of 5.4 ± 1.4 s when asked to estimate 5 s. Other time durations were estimated to be shorter than their actual times: (15 s; 13.0 ± 3.6. 30 s; 24.7 ± 8.2, 60 s; 47.8 ± 18.5). In the time comparison test, the mean correct number among eight tests was 6.59 ± 1.25 (Table 2). Among the four groups, patients with VCI/VD showed the most distorted times in all three-time perception tasks. Patients with abnormal z-scores in the MMSE and five cognitive domains also showed distorted time perception. In the attention and language domains, the verbal estimation test did not reveal any differences between the normal and abnormal groups.

3.1. Analysis I: neuropsychological test results according to disease subtype

Table 1 shows that the mean age was 73.0 ± 8.9, 73.4 ± 7.5, 74.5 ± 6.3, and 69.9 ± 8.2 years in the MCI/AD, VCI/VD, PDD, and SCI groups, respectively (p-value = 0.018). Despite no significant differences in years of education, the MMSE score was notably lowest in the VCI/VD group (22.4 ± 4.2, p-value <0.001). Additionally, they exhibited significantly lower digit span scores for Digits Forward (5.4 ± 1.4) and Digits Backward (2.8 ± 1.0), lower scores in the SVLT recall (12.7 ± 4.8) and delayed recall (2.1 ± 2.4), poorer performance on semantic fluency for animals (9.8 ± 3.8) and supermarket (8.7 ± 4.6), lower score on phonemic performance (13.5 ± 9.5), and the Stroop test for word reading (98.2 ± 25.0) and color reading (46.7 ± 28.3).

3.2. Analysis II: time perception test results according to disease subtype

Table 2 shows that the ability to perceive time differed between disease categories and the SCI group. In all verbal estimation tests, except the 5-s test, participants tended to perceive the duration as shorter than the actual duration. Patients with MCI/AD underestimated time in the 10-s (7.3 ± 2.9 s) and 15-s (10.7 ± 6.5 s) estimation task, while participants with VCI/VD underestimated time in the 35-s (19.6 ± 12.6 s) and 60-s (28.7 ± 19.9 s) estimation tasks, with these differences approaching statistical significance. For the

Table 2
Performance of Time perception test results according to the disease subtypes.

Disease type	Total	MCI/AD	VCI/VD	PDD	SCI	*p*-test
n	569	360	73	30	60	
Verbal Estimation Test						
5s	5.5 ± 2.5	5.3 ± 2.3	5.9 ± 3.5	5.2 ± 2.6	6.0 ± 1.9	**0.039**
5s error	0.5 ± 2.5	0.3 ± 2.3	0.9 ± 3.5	0.2 ± 2.6	1.0 ± 1.9	**0.039**
10s	7.5 ± 3.2	7.3 ± 2.9	8.0 ± 4.2	7.6 ± 5.2	8.3 ± 2.4	**0.026**
10s error	−2.5 ± 3.2	−2.7 ± 2.9	−2.0 ± 4.2	−2.4 ± 5.2	−1.7 ± 2.4	**0.026**
15s	11.2 ± 6.8	10.7 ± 6.5	12.0 ± 8.9	10.7 ± 5.5	13.3 ± 6.6	**0.002**
15s error	−3.8 ± 6.8	−4.3 ± 6.5	−3.0 ± 8.9	−4.3 ± 5.5	−1.6 ± 6.6	**0.002**
35s	23.5 ± 13.5	22.9 ± 12.8	19.6 ± 12.6	23.0 ± 11.6	28.8 ± 12.0	**<0.001**
35s error	−11.5 ± 13.5	−12.1 ± 12.8	−15.4 ± 12.6	−12.0 ± 11.6	−6.2 ± 12.0	**<0.001**
60s	39.3 ± 28.1	39.1 ± 28.5	28.7 ± 19.9	38.2 ± 25.4	48.8 ± 24.6	**<0.001**
60s error	−20.7 ± 28.1	−20.9 ± 28.5	−31.3 ± 19.9	−21.8 ± 25.4	−11.2 ± 24.6	**<0.001**
Time production test						
5s	5.4 ± 1.4	5.3 ± 1.3	5.7 ± 1.9	5.4 ± 1.8	5.5 ± 1.1	0.40
15s	13.0 ± 3.6	12.8 ± 3.5	12.7 ± 4.3	13.1 ± 3.5	14.7 ± 2.7	**0.001**
30s	24.7 ± 8.2	24.0 ± 8.1	23.6 ± 8.3	25.3 ± 9.6	29.0 ± 6.0	**<0.001**
60s	47.8 ± 18.5	46.9 ± 18.0	43.8 ± 18.9	47.2 ± 19.7	57.9 ± 14.8	**<0.001**
Time comparison test	6.59 ± 1.25	6.7 ± 1.2	6.0 ± 1.3	6.0 ± 1.5	7.1 ± 0.9	**<0.001**

The Kruskal-Wallis analysis was conducted to analyze the differences and interactions between groups.
Abbreviations: MCI = mild cognitive impairment, AD = Alzheimer's disease, VCI = vascular cognitive impairment, VD = vascular dementia, PDD= Parkinson's disease dementia, SCI = subjective cognitive impairment, MMSE = Mini Mental State Examination, BNT= Boston Naming Test, RCFT = Rey complex figure test, SVLT= Seoul Verbal Learning Test, COWAT= Controlled Oral Word Association Test.

time production task, no difference was observed between the groups in the 5-s test. However, participants with VCI/VD produced shorter times in their 15-s (12.7 ± 4.3; p value = 0.001), 30-s (23.6 ± 8.3; p value < 0.001), and 60-s trials (43.8 ± 18.9; p value < 0.001) (Fig. 1). In the time comparison task, participants with VCI/VD gave significantly fewer correct answers than the controls (6.0 ± 1.3 vs. 7.1 ± 0.9, p value < 0.001).

3.3. Analysis III: associations of time perception tasks with neuropsychological functions

To clarify the relationship between time perception testing and each neuropsychological function, linear regression analysis was conducted (Table 3).

In the MCI/AD group, a 60-s trial of the verbal estimation task, considered relatively lengthy, showed significant correlations with the RCFT copy score, SVLT immediate recall, COWAT animal, COWAT phonemic, and Stroop color reading test. Similarly, errors in time production during a 60-s test correlated significantly with the RCFT copy score, SVLT immediate recall, SVLT delayed recall, COWAT animal, and Stroop color reading test.

In the VCI/VD group, a 60-s trial of the verbal estimation task showed significant associations with the SVLT immediate recall, SVLT delayed recall, COWAT animal, and COWAT phonemic. In the time production test, a 5-s error correlated only with the COWAT phonemic score, with most other results showing no significant correlations.

To clarify the associations, participants were stratified into two groups based on the z-score of each cognitive domain using SNSB (Supplemental Table 4). Patients with abnormal z-scores in the MMSE and five cognitive domains exhibited distorted time perception, typically showing shorter time estimation and production and reduced accuracy in time comparison tests. No differences in the verbal estimation test were observed between the normal and abnormal groups in the attention or language domains.

3.4. Analysis IV: time perception tasks according to the MMSE score

Time perception is significantly influenced by factors such as age, social activities, emotions, and cognition. Therefore, to address these biases, participants were stratified into two groups based on their baseline cognitive function (MMSE score of >24 vs. relatively abnormal cognitive function, MMSE score of ≤24) (Supplemental Table 5). In the verbal estimation task, patients with an MMSE score ≤24 consistently estimated shorter times across all five tasks compared to those with an MMSE score >24, approaching statistical

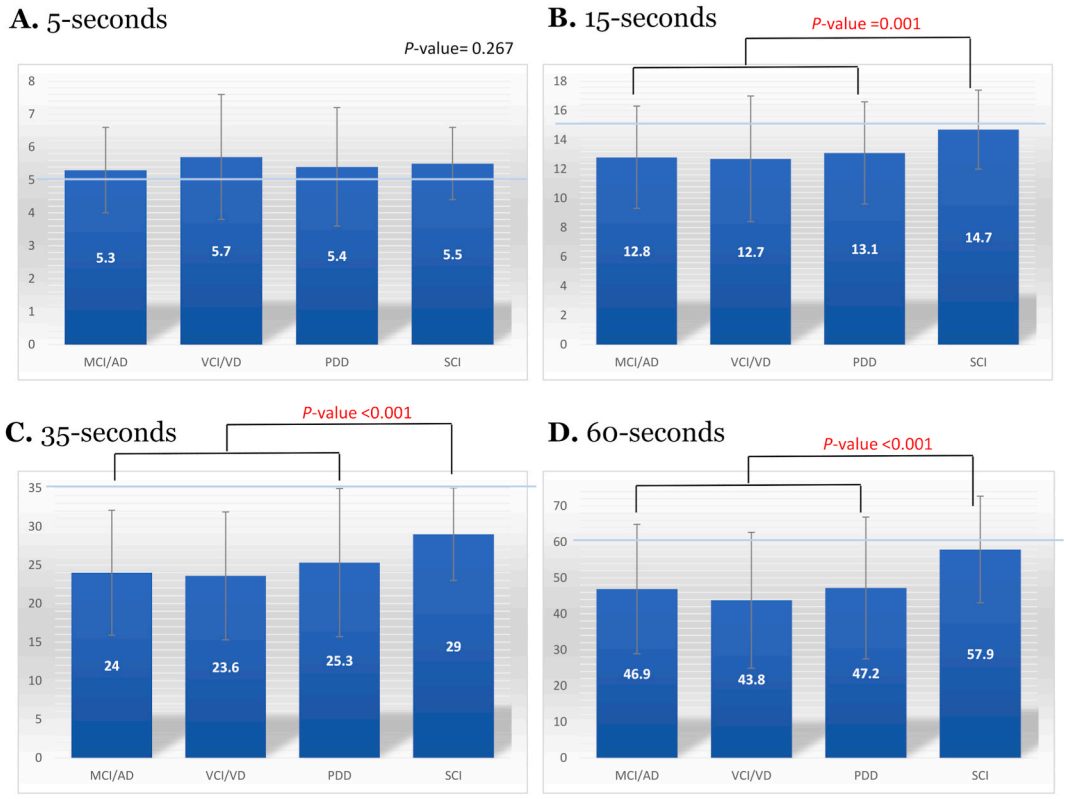

Fig. 1. Results of time production tasks.
There was no difference between groups in the 5-s test (A), but subjects with VCI/VD produced shorter times in their 15-s (12.7 ± 4.3; p value = 0.001) (B), 30-s (23.6 ± 8.3; p value < 0.001) (C), and 60-s trials (43.8 ± 18.9; p value < 0.001) (D).

Table 3
Associations of time perception performances with neuropsychological functions.

	RCFT copy		SVLT immediate recall		SVLT delayed recall		COWAT animal		COWAT phonemic		Stroop test for color reading	
	β(SE)	p value	β (SE)	p value	β (SE)	p value	β (SE)	p value	β(SE)	p value	β (SE)	p value
MCI/AD												
Verbal estimation test												
5s error	0.085 ± 0.178	0.633	0.042 ± 0.135	0.757	0.065 ± 0.078	0.405	0.337 ± 0.134	0.013	0.647 ± 0.311	**0.038**	1.891 ± 0.759	**0.013**
10s error	0.213 ± 0.127	0.095	0.175 ± 0.096	0.069	0.095 ± 0.056	0.089	0.070 ± 0.096	0.468	−0.031 ± 0.221	0.889	0.437 ± 0.541	0.420
15s error	0.034 ± 0.055	0.544	0.104 ± 0.042	**0.013**	0.039 ± 0.024	0.109	0.005v0.042	0.908	0.063 ± 0.096	0.513	0.381 ± 0.235	0.105
35s error	0.007 ± 0.033	0.823	−0.017 ± 0.025	0.481	0.020 ± 0.014	0.154	0.005 ± 0.024	0.851	−0.068 ± 0.057	0.228	−0.088 ± 0.138	0.523
60s error	0.036 ± 0.013	**0.007**	0.020 ± 0.010	**0.046**	0.011 ± 0.006	0.052	0.024 ± 0.010	**0.016**	0.072 ± 0.023	**0.002**	0.166 ± 0.057	**0.004**
Time production test												
5s	−0.402 ± 0.275	0.145	0.117 ± 0.208	0.575	0.054 ± 0.121	0.653	−0.102 ± 0.207	0.624	−1.377 ± 0.479	**0.004**	−3.182 ± 1.171	**0.007**
15s	−0.203 ± 0.198	0.304	0.007 ± 0.149	0.964	0.083 ± 0.086	0.339	0.135 ± 0.149	0.363	0.358 ± 0.344	0.298	1.722 ± 0.840	**0.041**
30s	0.229 ± 0.106	**0.032**	−0.149 ± 0.080	0.063	−0.085 ± 0.046	0.068	−0.108 ± 0.080	0.177	0.069 ± 0.185	0.710	−0.824 ± 0.451	0.069
60s	0.023 ± 0.037	0.529	0.089 ± 0.028	**0.002**	0.044 ± 0.016	**0.008**	0.064 ± 0.028	**0.022**	0.090 ± 0.065	0.166	0.440 ± 0.159	**0.006**
VCI/VD												
Verbal estimation error												
5s error	0.137 ± 0.416	0.743	−0.008 ± 0.241	0.973	−0.130 ± 0.123	0.294	−0.111 ± 0.195	0.573	0.373 ± 0.459	0.420	0.959 ± 1.471	0.517
10s error	−0.032 ± 0.317	0.921	−0.024 ± 0.184	0.894	0.026 ± 0.094	0.779	−0.087 ± 0.149	0.560	−0.250 ± 0.350	0.479	−0.158 ± 1.121	0.889
15s error	−0.228 ± 0.131	0.087	−0.079 ± 0.076	0.303	−0.048 ± 0.039	0.218	−0.043 ± 0.062	0.491	−0.115 ± 0.145	0.429	−0.658 ± 0.465	0.162
35s error	0.099 ± 0.132	0.459	−0.047 ± 0.077	0.547	−0.025 ± 0.039	0.521	−0.043 ± 0.062	0.734	−0.111 ± 0.147	0.452	0.354 ± 0.470	0.454
60s error	0.145 ± 0.086	0.097	0.175 ± 0.050	**0.001**	0.090 ± 0.025	**0.001**	−0.021 ± 0.062	**0.002**	0.315 ± 0.095	**0.002**	0.486 ± 0.303	0.114
Time production error												
5s	−0.641 ± 0.498	0.203	−0.506 ± 0.289	0.085	−0.276 ± 0.147	0.065	−0.215 ± 0.234	0.362	−1.272 ± 0.590	**0.035**	−2.522 ± 1.889	0.187
15s	−0.013 ± 0.372	0.973	0.144 ± 0.216	0.508	0.094 ± 0.110	0.398	−0.003 ± 0.174	0.989	0.094 ± 0.422	0.824	0.268 ± 1.352	0.843
30s	−0.082 ± 0.324	0.800	0.036 ± 0.188	0.849	0.073 ± 0.096	0.449	0.164 ± 0.152	0.284	0.055 ± 0.359	0.879	−0.532 ± 1.150	0.646
60s	0.107 ± 0.114	0.352	−0.024 ± 0.066	0.718	−0.044 ± 0.034	0.194	−0.050 ± 0.053	0.354	0.049 ± 0.129	0.704	0.476 ± 0.414	0.255

Abbreviations: MCI = mild cognitive impairment, AD = Alzheimer's disease, VCI = vascular cognitive impairment, VD = vascular dementia, MMSE = Mini Mental State Examination, BNT= Boston Naming Test, RCFT = Rey complex figure test, SVLT= Seoul Verbal Learning Test, COWAT= Controlled Oral Word Association Test.

significance. Regarding time production, participants with an MMSE score ≤24 produced shorter times in their 15-s (14.0 ± 3.4 vs. 12.0 ± 3.5; p value < 0.001), 30-s (27.3 ± 7.8 vs. 22.1 ± 7.7; p value < 0.001), and 60-s trials (53.8 ± 17.4 vs. 41.8 ± 17.6; p value < 0.001). In the time comparison task, participants with an MMSE score ≤24 gave significantly fewer correct answers than that given by the controls (6.9 ± 1.1 vs. 6.2 ± 1.3, p value < 0.001).

4. Discussion

In this study, time perception was distorted in patients with neurocognitive impairments, including AD, VD, or PDD, while those with distorted time perception exhibited temporal underestimation compared to controls. While all participants with degenerative diseases showed poorer time perception compared to the SCI group, the VCI/VD group demonstrated a significant error relative to the reference time index. The results of the time perception tests were significantly correlated with multiple neuropsychological functions. Therefore, we assume that the internal clock, attention, visuospatial, and frontal/executive function processes are variably affected during time perception tasks.

Verbal estimation and time production tasks are suitable methods for investigating the speed rate of the internal clock [20]. These two tests are employed to evaluate the individual speed rate of the internal clock [20]. However, verbal estimation is less accurate than time perception tasks because participants tend to round off the time interval [21]. Time comparison tasks primarily rely on the temporal cognitive process of working memory [17]. Moreover, attention and executive functions are necessary to distinguish between two temporal time durations accurately [17]. Time perception is closely associated with cognitive abilities, including attention, working memory [22], motor activity, psychological and emotional factors [23], and executive function [24].

In this study, participants with neurocognitive impairment (MCI/AD, VCI/VD, and PDD) demonstrated lower accuracy rates in time production, estimation, and comparison tasks compared to those in the SCI groups. Participants with VCI/VD exhibited the worst performance in time perception. Since time perception requires multimodal functions across diverse brain areas [8,25], our findings suggest that patients with VCI/VD experience neurological dysfunctions in focal and diffuse brain connectivity. This indicates that temporal impairment may not be solely owing to an internal clock but related to attentional, working memory, and executive dysfunctions. Previous studies show that patients with VD have more diffuse brain damage and disrupted connectivity across multiple brain networks compared to patients with AD. In the analysis of white matter structural networks using diffusion tensor imaging (DTI) and 3.0-T MRI, patients with subcortical ischemic VD demonstrated reduced structural connections in the frontal, prefrontal, and subcortical areas. In contrast, patients with AD had decreased structural connections in the temporal and occipital regions but increased structural connections in the frontal and prefrontal areas [26]. The reduction in structural connections in the temporal and occipital cortices of patients with AD could be related to functional deficits, while the increased structural connections in the frontal and prefrontal regions may serve as a compensatory mechanism for functional deficits [26].

Furthermore, an important question is which psychological function is closely associated with time perception. In this study, time perception performance was correlated with the RCFT copy, SVLT immediate recall, delayed recall, COWAT animal, COWAT phonemic, and Stroop test for color reading. RCFT reflects visuospatial function, SVLT indicates memory function, and COWAT and Stroop tests reflect frontal function. Therefore, precepting time was observed to require visuospatial memory and frontal/executive functions, which was consistent with previous study findings [1,22,27]. Additionally, based on the findings that no difference was observed in verbal estimation results between the normal and abnormal groups in the attention and language domain, we cautiously suggest that time production or time comparison tests may be more effective than verbal estimation test in evaluating these two domains.

In this study, participants overestimated short durations (5.3, 5.9, 5.2, and 6 s) in the 5-s verbal estimation task and overestimated seconds (5.3, 5.7, 5.4, and 5.5 s) in the 5-s time production test across each disease group. In contrast, participants underestimated longer intervals for time periods (>10 s). This phenomenon may be explained by Vierordt's law, which states that there is a tendency to overestimate short intervals and underestimate long intervals [28]. Recently, internal clock models consistent with the pacemaker-accumulator model of the Scalar Expectancy Theory have been used to elucidate the modality effect in timing. Temporal regulation of behavior is explained by proposing that animals possess a timing-specific internal clock-like mechanism, which can be started and stopped, and whose values maintain orderly relations to real-time [29]. Several studies demonstrate that the overestimation or underestimation of time duration is related to this "internal clock." Compared to young adults, children and older adults have a faster internal clock, which makes them tend to underestimate temporal intervals [24]. However, the potential influence of other factors should be considered. For example, patients with orbitofrontal cortex (OFC) damage significantly overestimated time, suggesting a faster sense of time, whereas a normal group underestimated time at the 90-s interval [30]. Furthermore, a previous meta-analysis indicates that time perception and basic temporal processing in patients with schizophrenia were slower than in the normal population [7].

The main strength of this study is that it is the first to investigate the associations between time perception and neuropsychological functions while considering domain-specificity. Most previous studies have only shown the clinical features of time distortion in one particular disease using a very small sample size [8,24,31]. We did not identify specific brain areas related to time perception; however, this suggests that time perception is not localized to a single brain area. Rather, it involves complex functions from various cerebral domains.

Despite these strengths, this study has some limitations. First, time perception is strongly associated with age, social activities, emotions, and cognition. The group with MMSE ≤24 was older (70 ± 9 vs. 75 ± 8) and had fewer years of education (10.3 ± 4.8 vs. 8.0 ± 5.0) (Supplemental Table 2), which might have influenced the results. To address this bias, the raw scores of the neuropsychological test results and z-scores were adjusted for age, sex, and years of education. However, a certain previous study indicate that age did not significantly affect time perception estimates [32]. Additionally, the disorientation of time, place, and person may occur sequentially

during cognitive decline. Early detection of isolated chronotaraxis may be a novel sign of cognitive decline. Therefore, early tests for time perception may be useful tools for screening temporal cognitive decline. Second, performing time perception tasks might be influenced by the cognition and motor speed of the patients, and these biases could not be sufficiently adjusted. Finally, methods to identify amyloid pathology were not used to classify patients with AD, limiting the generalizability of the results.

5. Conclusion

Patients with VCI had the worst perception of time. Furthermore, an important implication of the data is that various temporal abilities, including attention, working memory, and executive function, are necessary for accurate time perception. This generalization may be limited; however, our finding offers a novel and broad perspective on temporal time perception in patients with degenerative diseases. Our findings may contribute slightly to understanding the underlying pathophysiology and psychological connections related to the temporal abilities of time perception.

Data availability

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Ethics statement

As this study is retrospective in nature and does not involve administering interventions to patients and with no exposure of patients' personal information, the necessity for patient consent is not considered. However, ethical clearance was obtained from the Institutional Review Board (IRB), confirming the absence of ethical concerns.

The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Institutional Review Board from Kangdong Sacred Heart Hospital (IRB no. 2020-10-011).

Competing interests

The authors declare no conflicts of interest.

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CRediT authorship contribution statement

Yerim Kim: Writing – original draft, Visualization, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Jong Seok Bae:** Writing – review & editing, Supervision, Conceptualization. **Yeo Jin Kim:** Writing – review & editing, Methodology, Investigation. **Ju-Hun Lee:** Writing – review & editing. **Soo-Hyun Park:** Writing – review & editing. **Minwoo Lee:** Writing – review & editing. **Sang-Hwa Lee:** Writing – review & editing, Investigation. **Chulho Kim:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Not applicable.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e36002.

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