The potential of virtual reality techniques to assess and enhance functional autonomy in patients with Alzheimer's disease

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Introduction

- Alzheimer’s disease (AD) causes cognitive impairments affecting daily life autonomy.

- Initially, AD patients have difficulty with complex Instrumental Activities of Daily Living.
  I-ADL: making a cup of tea (Rusted & Sheppard, 2002)

- These deficits are followed by a progressive decline in Basic Activities of Daily Living.
  B-ADL: toileting (Millán-Calenti et al., 2012)

- These impairments are associated with serious consequences, including:
  - Caregiverburden (De Bettignies et al., 1993)
  - Institutionalization (Mast et al., 2004)
  - Depression (Adam et al., 2000)
  - Death (Noale et al., 2003)

Introduction

- Assessment of IADL/ADL in AD patients is mainly done with functional scales based on self- or informant-report, such as the Lawton-Brody IADL scale (Lawton & Brody, 1969).

- However, this method poses several problems (Mitchell et al., 2011) :
  - AD patients may underestimate their functional impairments because of anosognosia (Starkstein et al., 2010).
  - It also offers a very gross assessment of performance, instead of a precise characterization of ADL-IADL deficits (Giovannetti et al., 2008).

Introduction

- In clinical neuropsychology, few objective methods exist to assess ADL-IADL.
- Most neuropsychological tests have been developed to measure cognitive abilities in artificial situations.
- Consequently, these tests have low ecological validity and limited ability to predict actual functioning in ADL-IADL (Chaytor et al., 2006).

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Introduction

- In the same vein, few objective methods exist to increase autonomy in ADL-IADL in AD patients.

- Available neuropsychological “rehabilitation” interventions in AD are mainly restorative, aiming to “repair” cognitive functions (memory, etc.).

- The beneficial effects of this approach is frequently criticized (e.g. Stuss, 2011), the transfer of gains to the real life being very low (Cicerone et al., 2011, 2017; Spikman, 2017).

Our work

These arguments in mind, in our lab (LPPL), in collaboration with our colleagues of Polytech Angers (LARIS) and of the University Hospital of Angers (Memory Center), we used virtual reality to develop different non-immersive kitchen environments to :

- Assess AD patients abilities during the execution of a coffee-task
- Train AD patients autonomy in cooking activities

Virtual reality

- Virtual Reality (VR) is a technology that allows people to navigate and interact with computer-generated three-dimensional environments in real time (Yamaguchi et al., 2012).

- These environments could be similar to those encountered in real life, allowing the user to realize activities close to those encountered in real life (HyeonHui & KyeongMi, 2015)




Virtual reality

In addition, VR tools can be used to:

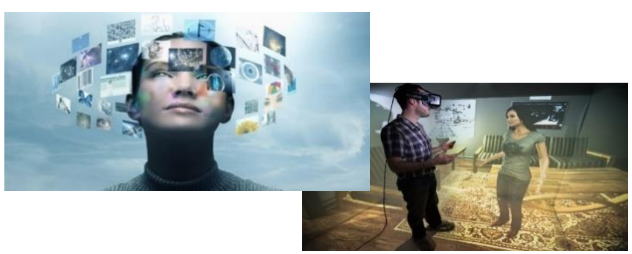
- ✓ Record accurate measurements of the subject’s performance
- ✓ Give real-time feedback on subject’s performance
- ✓ Deliver therapeutic stimulation to subjects




Virtual reality

Virtual Reality (VR) may then be very useful in the assessment/rehabilitation of ADL since it may increase :

- ✓ Ecological validity of assessment/training protocols
- ✓ Transfer of training gains to daily life



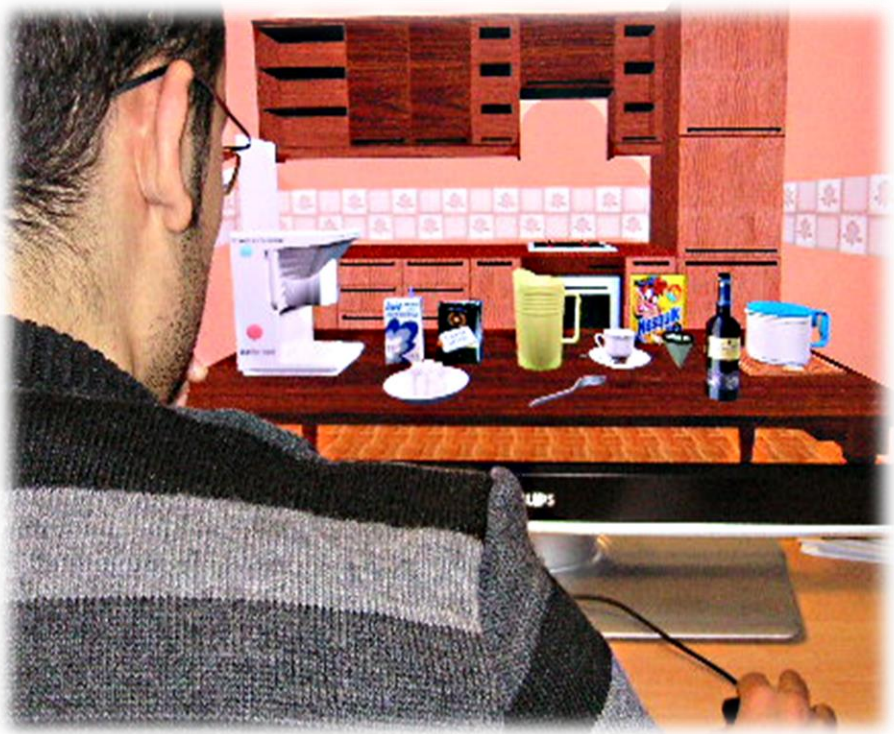
Our nonimmersive virtual reality kitchen

The user is seated in front of a screen monitor.

He first receives general verbal information about the assessment task and the virtual kitchen usage.

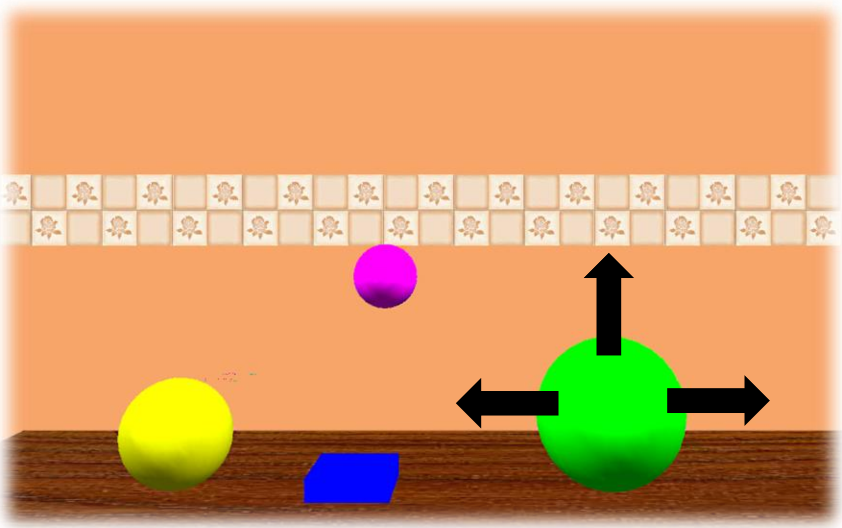
Then, he has to select and move virtual objects placed on a virtual table via the computer mouse.

Sound elements (water noise, noise from the coffee machine) are integrated in order to foster the sense of presence in the virtual environment.



Training session

A training session is available to enable the user to get acquainted with the virtual environment.



Move the objects with the mouse

Use the coffee machine with the mouse

Our task:

To prepare a virtual cup of coffee with milk and sugar, using a virtual coffee machine implemented in a virtual kitchen

Task

Open the coffee machine drawer (1)
Put the filter inside the machine (2)
Put the coffee powder on the filter (3)
Close the coffee machine drawer (4)
Open the water recipient (5)
Put some water in the machine (6)
Close the water recipient (7)
Put coffee recipient on machine (8)
Turn on the coffee machine (9)
Wait until the coffee is done (10)
Put the coffee in the cup (11)
Put back the coffee recipient (12)
Put a sugar in the coffee cup (13)
Put some milk in the coffee's cup (14)

User's actions are recorded in real-time and saved (.xls file).

Different outcome measures are calculated by the computer from data recorded while the user completes the task : the total time to complete the task, the number of errors (including omissions and commissions).

We also calculated an accomplishment score corresponding to the % of task steps completed with or without error.

Nom : ALLAIN
Prenom : Philippe
Date : 12/09/2010
Heure : 14:11:30

Temps	Action
0 min 38 s	Deplacement du pichet pour remplir la cafetiere
0 min 39 s	**Erreur, capot non ouvert lors du remplissage de la cafetiere avec le pichet**
0 min 41 s	Pichet repose
0 min 43 s	Demande ouverture du capot de la machine a café
0 min 43 s	Capot cafetiere ouvert
0 min 44 s	Deplacement du pichet pour remplir la cafetiere
0 min 45 s	Debut du remplissage de la cafetiere avec le pichet
0 min 49 s	Fin du remplissage de la cafetiere avec le pichet
0 min 50 s	Pichet repose
0 min 52 s	Demande fermeture du capot de la machine a café
0 min 52 s	Capot cafetiere ferme
0 min 53 s	Demande ouverture du bloc filtre
0 min 53 s	Bloc filtre ouvert
0 min 54 s	Deplacement du paquet de cafe vers le filtre
0 min 55 s	Debut du remplissage du filtre avec du cafe
0 min 55 s	**Erreur, bloc filtre rempli de cafe sans avoir positionne le filtre avant**
0 min 58 s	Fin du remplissage du filtre avec du cafe
0 min 59 s	Paquet de cafe repose
1 min 10 s	Demande fermeture du bloc filtre
1 min 10 s	Bloc filtre referme
1 min 12 s	Deplacement de la verseuse vers la machine
1 min 17 s	Verseuse deposee sous la machine
1 min 18 s	Demande de mise en marche de la cafetiere
1 min 18 s	Mise en marche de la cafetiere
1 min 24 s	**Erreur, demande de deplacement de la verseuse machine est en marche**
1 min 26 s	Cafetiere eteinte
1 min 27 s	Deplacement de la verseuse vers sa position initiale
1 min 28 s	verseuse revenu en position initiale
1 min 30 s	Deplacement de la verseuse vers la tasse
1 min 30 s	Debut du remplissage de la tasse avec du cafe
1 min 32 s	Fin du remplissage de la tasse avec du cafe
1 min 33 s	Verseuse reposee
1 min 33 s	Deplacement d'un sucre vers la tasse
1 min 35 s	Sucre depose dans la tasse

Le patient a fait du cafe en 1 min 37 sec avec 3 erreurs.

Virtual Kitchen and Alzheimer's disease

The virtual kitchen was first used to assess the ability of 24 patients with Alzheimer's disease (AD patients) and 32 healthy elderly to prepare a cup of coffee.

Identical real daily living task was tested in a real kitchen and scored following the same procedure in both groups.

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Detecting Everyday Action Deficits in Alzheimer's Disease Using a Nonimmersive Virtual Reality Kitchen

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Demographic and neuropsychological characteristics of participants

	AD patients (n = 24)			HE controls (n = 32)			Statistical testing	
Variables	*M*	*SD*	Range	*M*	*SD*	Range	F	*P*
Age	76.96	6.05	63–87	74.13	5.93	65–88	3.07	.08
Gender								
Male	10	/	/	7	/	/	/	/
Female	14	/	/	25	/	/	/	/
Years of School*	9.29	2.90	7–15	9.63	1.45	7–15	0.31	.57
MMSE (max = 30)	21.80	2.54	18–26	29.06	1.08	26–30	216.96	.0001
FAB (max = 18)	12.25	2.42	8–17	17.25	0.92	15–18	115.35	.0001
IADL* (max = 4)	2.42	1.26	1–4	3.87	0.33	3–4	38.43	.0001

Note. Years of school are calculated since the first grade.
*Data were missing for five AD patients.

Results

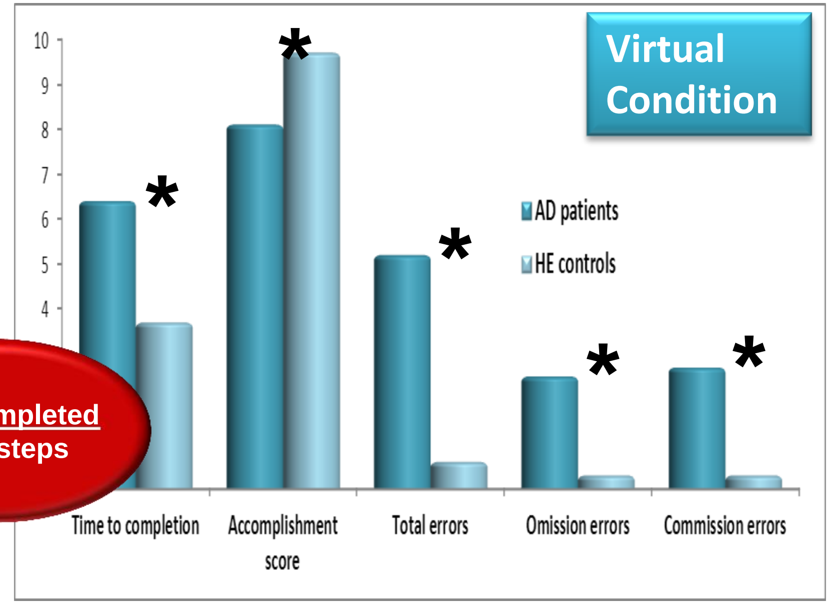
Table 2. Results of VCT and RCT tasks for AD patients and HE controls

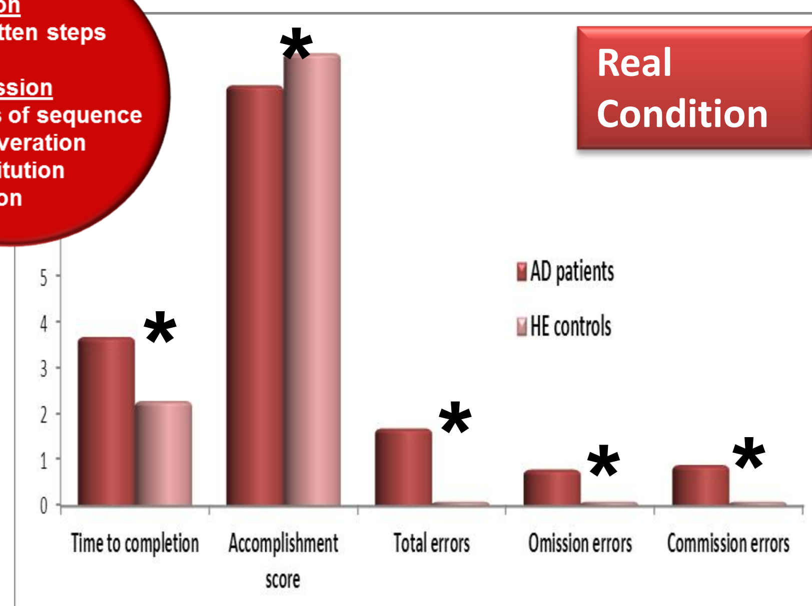
Condition	Dependant variables	AD patients (n = 24) *M*	AD patients (n = 24) *SD*	HE controls (n = 32) *M*	HE controls (n = 32) *SD*
VCT					
	Time to completion in seconds	647.33	253.35	374.06	162.18
	Accomplishment score (%)	81.45	19.44	97.59	5.79
	Total errors (number)	5.25	3.85	0.62	0.87
	Omission errors (number)	2.50	2.68	0.31	0.69
	Commission errors (number)	2.75	1.70	0.31	0.53
RCT					
	Time to completion in seconds	379.66	203.45	239.75	50.35
	Accomplishment score (%)	92.71	10.62	99.56	1.72
	Total errors (number)	1.71	1.92	0.15	0.51
	Omission errors (number)	0.79	0.83	0.06	0.24
	Commission errors (number)	0.91	1.01	0.09	0.29

Step completed
Total steps

Omission
- Forgotten steps

Commission
- Errors of sequence
- Perseveration
- Substitution
- Addition





Results : correlations with cognitive measures

	AD patients		HE controls	
	MMSE	FAB	MMSE	FAB
VCT				
Time to completion	-.48**	-.12	-.40*	-.10
Accomplishment score	.31	.25	-.19	-.13
Total errors	-.58***	-.62***	.06	.20
Omission errors	-.49**	-.46**	.18	.12
Commission errors	-.41*	-.54***	-.14	.16
RCT				
Time to completion	-.26	-.15	-.20	-.06
Accomplishment score	.09	.25	.25	.07
Total errors	-.51**	-.55***	-.16	-.33
Omission errors	-.54***	-.39*	-.25	-.07
Commission errors	-.40*	-.61***	-.22	-.32

Note. MMSE = * $p \leq .05$, ** $p \leq .01$, *** $p \leq .005$

Results : ecological validity (AD patients)

Multiple regression analyses revealed that :

- The virtual total errors score was the only predictor of the total real errors score (48% of the variance; F = 20.33; p = .0002)

- The virtual total errors score was the only predictor of the IADL score (29% ot the variance; $F = 8.68$ $p = .009$)

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Virtual reality training

- There is evidence that VR training transfers to real world situations :

  McComas et al. (2002), Katz et al. (2005): Post-stroke patients (children and adults), who practiced street-crossing through VR showed an improvement in their ability to cross a street safely in the real world.




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Virtual reality training of IADLs

In our lab , we also develop a virtual-reality based system to help AD patients to “relearn” cooking activities.

Virtual reality training of IADLs

The system includes 10 cooking tasks broken down in 12-15 actions:

- Laying the table for 2 people
- Preparing a cup of coffee with a coffee machine
- Preparing a cup of coffee with an espresso machine
- Preparing a cup of sweet tea using a kettle
- Preparing breakfast
- Preparing a salad with three ingredients
- Heating up soup in a microwave
- Preparing frozen vegetables with an electric stove
- Preparing a sandwich
- Cooking a chocolate cake with an electric oven

Virtual reality training of IADLs

For example, in the "Soup" task, the subject has to heat up the soup and serve 2 ladles of soup in the soup dish following 12 steps :

1. Open the jar of soup
2. Pour the soup into a terracotta container
3. Put the empty jar in the bin
4. Open the door of the microwave oven
5. Put the container in the oven
6. Close the door of the microwave oven
7. Press the red button
8. Wait for the oven to stop
9. Open the door of the microwave oven
10. Put the container on the trivet
11. Put a ladle of soup into the soup dish
12. Put another ladle of soup into the soup dish

Virtual reality training of IADLs

The system includes **a virtual kitchen** and the required **virtual objects for each cooking task** (i.e., foods, utensils; automatically displayed according to the task selected from the main menu).

Virtual reality training of IADLs

The system includes **a simple system of interactions**:

- Simple actions (turning on/off buttons), are performed by pressing the left button of a computer mouse.
- Virtual objects are moved by sliding the mouse, and by maintaining the left button down to keep hold of the object.

Virtual reality training of IADLs

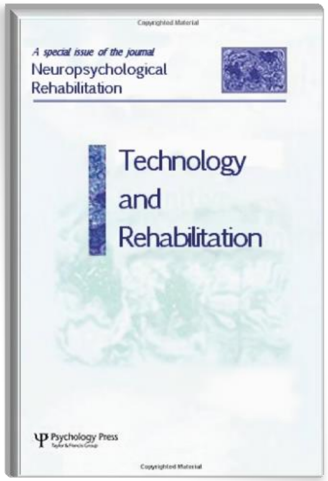
The system includes an original learning method combining **vanishing cues technique** and **errorless approach**.

In this method, several strategies are used to limit the risk of error :

1. The whole cooking task is demonstrated to the patient at the beginning of each session.
2. Then, the subject is asked to performed all the steps (actions) of the cooking task.
3. Ten seconds are given to the subject to perform each correct step.
4. If the subject does not perform the expected step within 10 seconds, a cueing method is used in order to draw his attention to the correct step to perform.

   For each step, 4 types of cue could be serially provided, until the subject performed the expected action (Table 1).
5. If the subject does not perform an action after 4 cues, it is automatically performed by the system.
6. Errors are avoided as soon as they are detected by the system.

Order	Successive cues for each step	Virtual reality
1	Oral instruction	An artificial voice reads the instruction
2	Written instruction	A written message appears on the screen
3	Showing the target object	A large green circle appears around the object
4	Demonstration of the movement	A demonstration video is played
5	Performance by a third party	The action is automatically performed by the system



Virtual reality training: A case study

The potential of virtual reality-based training to enhance the functional autonomy of Alzheimer's disease patients in cooking activities: A single case study

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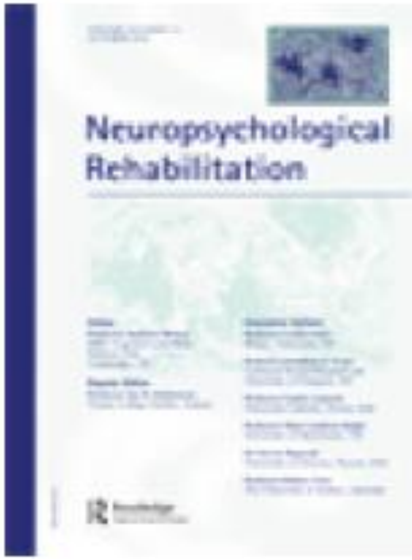
- ✓ **The study**
  - ✓ A 79 year old woman with Alzheimer's Disease
  - ✓ Trained in 4 cooking task/4 days/1 hour per day
- ✓ **Results**
  - ✓ She could relearn cooking activities using VR techniques
  - ✓ Tranfert to real life was observed
  - ✓ Improvement of the task performance remained stable over time.



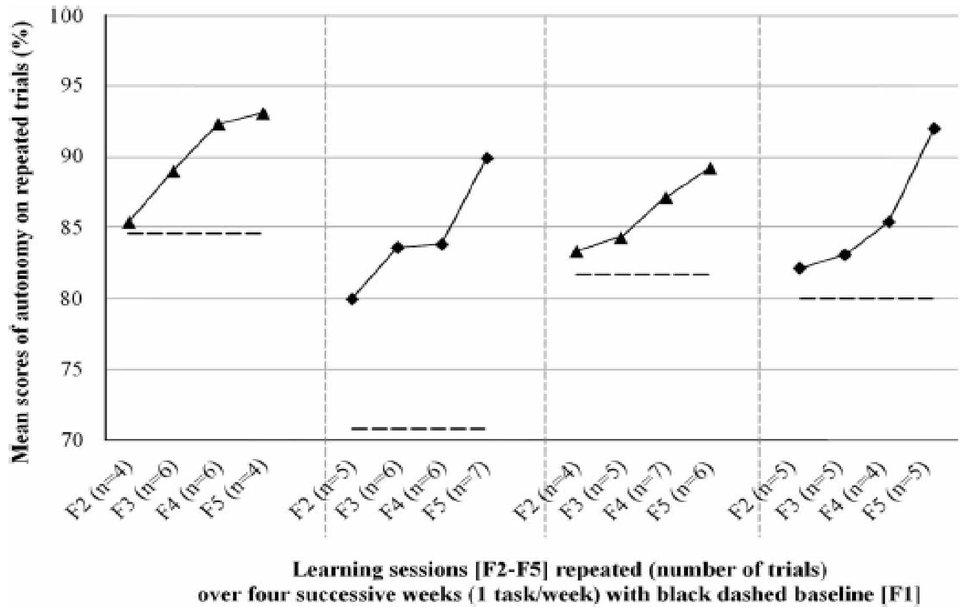


Figure 4. Mean scores of autonomy on repeated trials for each day session (F2–F5) over the four successive weeks (1 task/week) and the dashed baseline score (F1).
Note: The graphs using triangles as dots represent measurements of learning in real conditions. The graphs using diamonds as dots represent measurements of learning in virtual conditions.

Perspectives :
- To publish converging results obtained with a group of AD patients
- Group study with other types of neurological patients

Conclusions and perspectives

- Our results provide additional support for the utility of virtual environments for assessment/rehabilitation of IADL in AD patients.
- By now, we try to confirm these data with other types of brain-damaged patients and with other daily life virtual tasks (prospective memory tasks, social cognition tasks).

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Thank you for your attention

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