Current Psychology (2023) 42:29230–29241
https://doi.org/10.1007/s12144-022-03963-6

The Padua PM task: a new high-quality video-based prospective memory assessment in younger and older adults

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Accepted: 30 October 2022 / Published online: 15 November 2022

Abstract
Older adults are particularly compromised when engaged in Prospective Memory (PM) tasks, but it has also been pointed out that age-related PM decline is mainly observed in experimental settings (laboratory vs. naturalistic settings). Here, we present the Padua PM task, a new "real life" video-based assessment designed to investigate age-related PM changes in an ecologically valid but still well controlled way. The task requires participants to remember to perform event-based and time-based activities while watching short videos. The Padua PM task includes three different conditions namely "*Standard condition*", "*Event-based High Demand*" (HD) and "*Time-based High Demand*" (HD) that aim to disentangle age-related PM impairment in older adults as a function of cognitive demand and of the monitoring requirements for intention retrieval. Participants (20 young adults mean age: 22.35 years and 20 older adults mean age: 68.90 years) were tested with a classical PM task (i.e., an *n*-back PM computerised task) and with the new Padua PM task. Results confirmed a lower PM performance in older adults compared to their younger counterparts. Older adults also showed a worse performance, than young ones, when the cue was time-based task compared to the event-based in the *n*-back task (laboratory task), but they showed an opposite pattern of performance in the Padua PM task (event-based and time-based HD conditions; video-based task). Time-based tasks were not necessarily more attentionally demanding than event-based tasks, but the involvement of attentional resources seemed to differently influence performance in different task types. It is concluded that the Padua PM task may serve as a useful tool to further investigate age-related differences in PM performance in the laboratory while using naturalistic task material.

Keywords Prospective memory · Aging · Naturalistic tasks · Laboratory-based task · Padua PM task

Introduction

Prospective memory (PM) refers to memory for future intentions, such as remembering to take medications or to turn off appliances, and is therefore critically linked to functional independence and wellbeing in particular

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for older adults and their everyday quality of life (Hering et al., 2018; Woods et al., 2015). The present study aimed to investigate PM performance in young and older adults by comparing performances in a standard laboratory PM paradigm i.e., *n*-Back PM tasks (Kliegel & Jäger, 2006) and a new high-quality "real" video-based PM task i.e., Padua PM task.

Experimental studies on age differences between young and older adults have yielded inconsistent results, and the effect of ageing on PM remains a complex and unresolved puzzle. First, several studies have suggested that the realization of delayed time-based PM intentions (i.e., intended action to be performed after a certain moment in time or after a certain time period) is more affected by ageing than the recall of event-based ones (i.e., intended action to be performed when a specific event occurs) (Brandimonte et al., 2014). These results are in line with the hypothesis that time-based PM tasks require more self-initiated process and benefit less from environmental support as observed in event-based PM tasks. This stronger age-related impairment in older adults for time-based intentions has notably been attributed to the difficulty that older individuals may with monitoring the clock (Mioni & Stablum, 2014; Mioni et al., 2019). However, a few studies have also reported the reverse pattern, with older adults having greater difficulty recalling event-based than time-based intentions. These contradictory results have been attributed to the characteristics of the PM tasks and the diversity of processes involved in the retrieval of intentions in time-based or event-based PM tasks (for reviews and meta-analyses of PM functioning in older adults see: Henry et al., 2004; Ihle et al., 2013; Kliegel et al., 2008, 2016; McDaniel & Einstein 2007, 2011; Uttl, 2011; West, 2011). Haines and colleagues (Haines et al., 2020 –Experiment 1), for instance, recently compared younger and older adults on three different time-based PM tasks using comparable PM activities on virtual setting, daily life narrative and a customized smartphone application in actual daily life. The results showed that the pattern of age-effects differed across settings depending on a combination of PM task setting and type of cue; in particular, older adults outperformed younger using the smartphone application in actual daily life setting, but performed worse than young adults in the laboratory.

A possible source of discrepancy between studies in understanding age-related PM decline may thus be related to the setting, and in particular comparing laboratory vs. naturalistic settings. Even if the general structure of laboratory-based PM paradigms resembles everyday experiences (e.g., to buy the milk on a way home from work when passing a supermarket = to remember to press a certain key when a specific word occurs during the lexical decision ongoing task) while being engaged in everyday life (simulated by the ongoing activity), most of the PM laboratory paradigms have little resemblance to real-life situations and remain abstract, artificial, non-familiar, and novel to the participants.

The discrepancy in ecological validity is even more evident when older adults are tested. Only a few studies have tested, in and outside the laboratory, the same samples of young and older adults (Kvavilashvili et al., 2013; Niedźwieńska & Barzykowski, 2012; Rendell & Thomson, 1999; Schnitzspahn et al., 2011), and even fewer studies used both time-and-event-based tasks within the single study design (Niedźwieńska & Barzykowski, 2012; Schnitzspahn et al., 2020; Rendell & Craik, 2000).

One aspect contributing to the discrepancy in ecological validity is that paradigms can differ widely in their degree of naturalistic properties. Phillips et al. (2008) suggested, in fact, different levels of ecological validity in laboratory and naturalistic tasks. Besides the setting, the authors classified tasks according to their familiarity in everyday life and whether the tasks are artificial or naturally occurring as having higher or lower ecological validity. For example, a laboratory task could be more familiar and resemblance more naturally occurring tasks, making it to be more ecologically valid. A task could be naturalistic but have a lower degree of ecological validity because it is unfamiliar and artificial (e.g., logging times in an organizer, Rendell & Thomson 1999). Further, as recently argued by Kvavilashvili and Rummel (2020), naturalistic tasks are limited by their reduced experimental control making them fewer objective measures. A first attempt to reduce the discrepancy between laboratory vs. naturalistic settings was done in studies using Virtual Week (Rendell & Craik, 2000). Virtual Week is a computer-based task that simulates daily life activities using a board game format. Participants move around the board with the roll of a dice; each circuit around the board represents one virtual day. Virtual Week has been extensively used in healthy and clinical population (Rendell & Henry, 2009) and demonstrated a high reliability and internal consistency (Rose et al., 2010). Despite Virtual Week includes PM tasks that resemble everyday activities it is structured as a boardgame with reduced resemble with real-world experiences. The present study aimed to overcome these limitations by introducing a new more naturalistic PM task for the laboratory.

An interesting way to increase the understanding of age-related PM decline in a controlled setting is by employing computer-generated artificial environments. Recently, researchers have thus begun to build and apply virtual environments (either immersive or video recorded environment) to the better understand PM performance with the perspective of further developing effective procedures that depend on reliable cognitive assessment methods. Virtual technology offers higher levels of realism and a great level of experimental control than naturalistic settings (Rizzo et al., 2020). Ouellet and colleagues (Ouellet et al., 2018) implemented an immersive virtual reality environment resembling a shop. Young and older adults were presented with a list of items to buy at the shop (PM task); older adults were less accurate, also they required more time to complete the task. Despite the advantages of virtual environments in filling the gaps between laboratory and naturalistic setting, these devices gave rise to several limitations with older adults sometimes not being familiar with advanced technology (Jayroe & Wolfram, 2012; Wolfson et al., 2014) and experiencing discomfort and motion- or cybersickness (Kin et al., 2017).

A way to overpass these limitations is using high quality videos of real-life situations in which participants can navigate and perform the PM activities. Video-based assessments have the advantage to be less demanding in terms of computer skills and participants do not experience negative side effects as reported in immersive virtual reality studies (Huygelier et al., 2019; Kin et al., 2017). Importantly, using video-based assessment, it is still possible to manipulate critical features such as task demands and cue features that are critical indices to fully understand age-related PM performance.

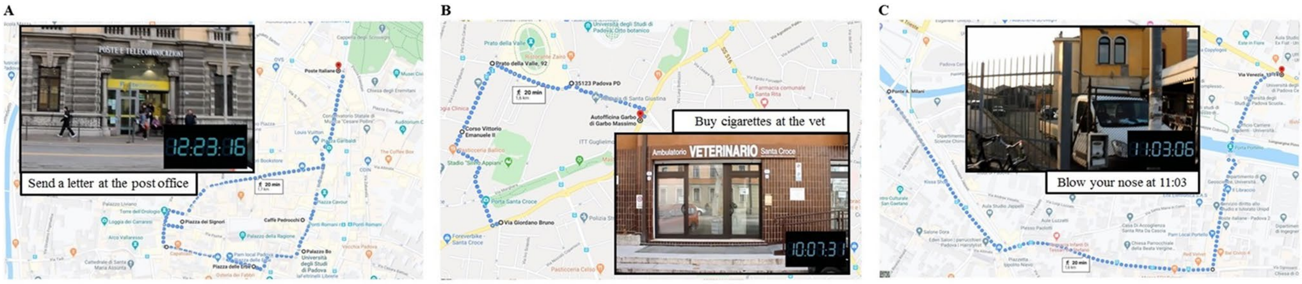
Only few studies have used video-based assessment in aging; McDermont and Knight (2004), for instance, asked three groups of older, middle-aged, and young persons to remember a list of 27 instructions, each comprising an action and associated cue with a high degree of association (i.e., if the action was "Buy a hamburger" the cue was "McDonald"). Participants were instructed to watch a video and to recall each task when the cue appeared (only event-based PM tasks). The authors hypothesized that noticing the cues should rely on spontaneous or automatic processing due to the familiar context, whereas retrieving the tasks should require more resource demanding search processes susceptible to age differences. Results showed that older participants were less accurate than younger and middle-aged participants for both noticing the cues and recalling the task. Specifically, older adults were more impaired in remembering the correct action than noticing the cue indicating that especially more resource demanding processes are driving age differences. Similarly, Ferrimond and colleagues (Ferrimond et al., 2006) tested younger and older participants using a virtual street computerised procedure in which a series of 1500 images of a shopping street were assembled, and participants could move through using a touch screen. Results showed no group difference in their ability to detect cues, but older adults were less accurate than the younger group to recall the correct action associated with the correct cue. Both studies suggest that more naturalistic laboratory tasks are useful to detect age differences, and furthermore, to identify potential causes for these differences. However, both studies lack in the comparison between event- and time-based cues and whether cue detection/action retrieval relied on strategic versus spontaneous processes.

One important mechanism that is used to explain age differences in PM retrieval between young and older adults in the laboratory is the engagement of strategic versus spontaneous processes (McDaniel & Einstein, 2000). Depending on task properties, PM tasks could require more strategic monitoring versus more spontaneous processes (e.g., orienting response) for the detection of the PM cue, which amplifies age differences in younger and older adults (Ball et al., 2020; Scullin et al., 2011). Similarly, in time-based tasks, monitoring the time requires attentional resources imposing higher demands on task execution, which also accentuate age differences in younger and older adults (Mioni & Stablum, 2014; Mioni et al., 2019). Also, the demand for the retrieval or memory search for the intention could vary from strategic or spontaneous processing. One such task property, that is considered to influence whether a task relies on more or less monitoring for retrieval, is the association between the PM cue and the intended action (e.g., McDaniel et al., 2004). The cue-action association is also relevant in naturalistic PM tasks. It is easily imaginable, for instance, that someone will remember to buy bread when passing a bakery on the way home after work; however, to buy bread when passing by a gas station on the way home might be more easily forgotten.

Thus, despite some progresses in research on aging and PM performance, there are several unanswered questions not only in terms of the exact pattern of the age-related changes in young and older adults in time- and event-based tasks but also in terms of potential variables (i.e., cue distinctiveness) that are critical in determining the degree of age-related effects in more ecological valid tasks in the laboratory resembling naturalistic settings.

The present study aimed to respond to these questions by presenting a new paradigm for laboratory-based testing using a high-quality video-based assessment recorded in the naturalistic setting and resembling everyday PM requests. Our work in fact aimed at the development of a video-based assessment for use in investigating the age-related PM differences and difficulties (if any) in older adults and to present a procedure that captures the real-life complexity of PM in an ecologically valid way. We wanted to further investigate age-related PM differences in young and older adults using a more naturalistic tool that resamples everyday activities. Also, we were interested in testing the diversity of processes in terms of cue-action association involved in the retrieval of intentions in event-based and time-based tasks as a potential mechanism to explore age differences between young and older adults typically found in the laboratory.

This study employed video-based technology to construct a PM procedure using naturalistic stimuli (video of an unfamiliar city) in which PM tasks that can be considered typical of everyday life were presented. We designed a new PM task, named the Padua PM task; it includes both event- and



List of activities
Video starts at 12:20
- After 1 minute remember to take the medication (12:21)
- At the post office send a letter (12:23)
- At 12:26 call your husband/wife (12:36)
- At the shop top-up your self-phone (12:27)
- Pick up your niece after 4 minutes (12:31)
- Buy the potatoes in «Piazza della frutta» (12:34)
- At 12:36 remember to ask for exact time (12:36)
- Get a taxi to the airport at the taxi station (12:39)

Video ends at 12:45

List of activities
Video starts at 10:00
- At the mechanic, ask to print your ID (10:01)
- Call your doctor at 10:05 (10:05)
- At the vet, buy sigarette (10:07)
- Text your son at 10:10
- At the supermarket, tie your shoes (10:11)
- Get a new watch in 4 minutes (10:15)
- At bakery, get a new shirt (10:17)
- At 10:20 call your friend for his birthday (10:20)

Video ends at 10:25

List of activities
Video starts at 11:00 :
- At the mechanic, ask for car checking(11:01)
- At 11:03 blow your nose (11:03)
- When at «piovego» take a picture at the river (11:06)
- After 2 minutes buy a post card (11:08)
- Order a coffee at "Portello bar" (11:11)
- After 4 minutes check your shopping list (11:15)
- At the farmacy, buy medication for your allergy (11:16)
- Have a snack at 11:18 (11:18)

Video ends at 11:25

Fig. 1 Padua PM task. **A** "*Standard condition*" in which the content of the event-based activity was conceptually connected with the PM cue and the time-based activity occurred regularly every 5 min. **B** "*Event-based-HD*" (high-demand) condition in which the content of the event-based activity did not match with the PM cue and the time-based activity occurred regularly every 5 min. **C** "*Time-based-HD*" (high demand) condition in which the content of the event-based activity was conceptually connected with the PM cue but the time-based activity occurred at irregular time-points (i.e., after 2 or 4 min or at 11:03 or 11:18). For all images, dots-line indicates the path

time-based tasks within the same experimental procedure and we manipulated the degree of the task complexity, in terms of requests, on both event and time-based tasks. In detail, participants were asked to watch three videos of the Padua town (Italy) showing pathways through the city in which participants see different shops, houses and parks, and listen simultaneously to a recorded voice describing the city, local food, and local cultural events. As ongoing task, participants were instructed to carefully listen to the recorded voice because after the videos they were asked to respond to 10 true/false questions about the content of the presentation. As their PM task, they were asked to remember to perform actions at specific time (time-based cues) or when specific target appears (event-based cues) by pressing a designed key on the keyboard (i.e., the spacebar) and to say aloud the PM action. Because of the role of compensatory strategies that may influence memory and PM performance (Masumoto et al., 2011), we recorded the number of times participants checked the list of PM activities to control participants' PM strategies (see Fig. 1). In such a way, a corollary aim was to examine whether monitoring strategies may influence PM performance in young and older adults.

Three different conditions were defined for the Padua PM task namely "*Standard condition*", "*Event-based High Demand*" (event-based HD) and "*Time-based High Demand*" (time-based HD). Introducing these three different conditions could allow disentangling age-related PM impairments in older adults in event and time-based tasks as a function of cognitive demand and monitoring requirements for retrieval. In the event-based task, the cue-action association was manipulated, whereas in the time-based tasks, the time-cue was either more or less regular to increase monitoring demands similarly to the event-based manipulation. Briefly, the Standard condition was used a baseline of participants' PM performance. Participants were asked to press a key every 5-min (time-based task) and for the event-based condition, the delayed intentions were associated with a cue. The event-based HD condition included the same time-based PM task as in the standard condition, but we manipulated the cue distinctiveness using non-related cues; this was done to manipulate only the process involved in the retrieval of intentions. Finally, the time-based HD condition included the same event-based PM task as in the standard condition, but we manipulated the type of time-based task by asking participants to press the key after a set time (i.e., at 11:30 pick up the dry cleaning) or after a specific amount of time (after 2 min call the doctor) this was done reduce the regularity of time monitoring (following Rose et al., 2015).

More specifically the present study examined age related differences in young and older adults in:

(1) a computerised and naturalistic video PM tasks. All participants took part in a laboratory session where they completed a classical experimental measure of PM, a *N-Back PM task* (Kliegel & Jäger, 2006), and the new PM task, the *Padua PM task* developed and used as measure of real-life-like PM task. We predicted age-related differences between young and older adults, in favour of the younger, in the computerised condition (*n*-back PM task); moreover, we predict lower PM

performance in time-based compared to event-based in particular in older adults. We investigated whether the naturalistic task, attenuated age differences or not between young and older adults in the naturalistic condition (Padua PM task); based on other work using more familiar tasks in errand planning (Kliegel et al., 2007), we expected an attenuation of differences between the two age groups.

(2) in high-quality video-based PM task when more demanding event-based and time-based activities have to be performed. We predicted a lower performance in older adults compared to younger participants in event-based HD and time-based HD condition in particular when the PM activity was event-based in the Event-based HD, and when the PM activity was time-based in the time-based HD condition. These conditions require more monitoring –related to the lower cue association and time irregularity, respectively– for retrieval processes than the standard one. Finally, the influence of strategies by checking the PM task lists was examined, with the hypothesis that list checking would benefit performance, in particular for older adults (i.e. Hertzog et al., 2008), in both PM tasks and especially in the HD conditions.

Method

Participants

Twenty young adults (mean age: 22.35 years; SD = 2.01; 10 females) and 20 older adults (mean age: 68.90 years; SD = 3.46; 10 females) took part in the study. All participants were native Italian speakers and they were recruited in the local communities of Puglia and Campania (south of Italy). None of the participants were familiar with the city of Padova that was used to create the videos. Older adults were healthy community-dwelling individuals. For older adults, inclusion criteria were: an age over 65, and a score over 25 at Mini-Mental Status Examination (Folstein et al., 1975). All older adults reached the criteria to be included in the study and scored above the age-and education-adjusted MMSE normal cut-off (Measso et al., 1993), suggesting a normal cognitive functioning. Years of education were not significantly different in the age two groups [$t(38) = 1.09$, $p = .283$; young adults = 16.10 (2.22); older adults = 17.40 (4.85)]. Older participants had a higher vocabulary score (Wechsler vocabulary test; Wechsler, 1981) than younger adults [$t(38) = 1.09$, $p = .042$; young adults = 50.45 (9.20); older adults = 55.65 (6.12)], in line with age-related maintenance of vocabulary skills in aging.

Materials

N-back PM task

Two versions of the *n*-back PM computerised task, developed by Kliegel and Jäger (2006) were used. The tasks included the *n*-back working memory task as the ongoing task in which the two PM task types (event-based and the time-based PM task) were embedded. In the present study, we used a 2-back version of this task: Participants viewed pictures - pseudo-random sequences of the Snodgrass and Vanderwart (1980) - on a computer screen, each displayed for 4 s with 1 s ISI. Response keys were the left and the right arrows labelled with a "yes" and "no" markers respectively. Participants were instructed to press a "yes" key if the picture was the same as that which occurred twice before, otherwise a "no" key had to be pressed. The 2-back task consisted of 122 trials (maximum hits = 40). The number of correct responses was obtained by adding correct rejections and hits for each participant.

(1) The event-based PM task was to remember to press a target key whenever a picture depicting an animal appeared during the 2-back task. There were 5 PM targets, which occurred at 1:50, 3:50, 5:50, 7:50, and 9:50 min after the start of the ongoing task in order to closely parallel the occurrence of the event-based PM targets to the time-based PM target times (see below). Every hit on the target key that occurred within 5 s after the presentation of a PM target was scored as PM hit (range equals zero to five).

(2) The time-based PM task was to remember to press a target key at 2 min intervals from the start of the 2-back task as accurately as possible. To monitor the time, participants could press the "space" key to see a time counter clock ["00:00"] which appeared for 3 s. Every hit on the target key that occurred within a time window of five s ($\pm$ 2.5 s) around the PM target times was scored as PM hit (range equals zero to five).

Padua PM task

We created three videos of three different areas of the city centre of Padova. Each video lasted approximately 20 min; participants were instructed to watch the video and to listen to the audio describing the surrounding environment (ongoing task). Participants were also informed about the PM activities to be performed during the task. They could read and memorise the list of PM activities written for three minutes. The sheet was then turned but left next to the participants who could check the list any time they wished. The experimenter recorded the number of times the sheet was turned. The score was included into the analyses.

Ongoing task Participants were instructed to listen to the audio and to answer a questionnaire with 10 multiple-choice questions at the end of each audio (one audio per video). This was done to engage participants during the ongoing task and to avoid constant rehearsal of the PM activities. The audios reported general information about the city including historical or cultural events[1].

In each condition participants were instructed to perform eight PM activities (4 event- and 4 time-based). A list of activities was presented at the beginning of each video, participants were asked to read aloud and they had 3 min to memorised the activities. Participants were also instructed that they were allowed to check the list whenever they needed during the task. For event-based task, participants had to respond by pressing a key when the event-based cue appeared on the video and within five seconds after the event-based cue was on the screen (i.e., when you are at the post office send the letter, Fig. 1); in the case of time-based task, participants had to press the key at the target time or within five seconds. Participants could check the time by monitoring the clock displayed at the bottom right corner of the computer screen (event- or time-based target) and they were also instructed to say aloud the content of the to be remembered PM action. For example, if they were instructed to send the letter at the post office, they were instructed to press the spacebar when the post office was visible on the video and also to say aloud: "send the letter" (Event-based PM), similarly, if they were instructed to have a snack at 11:18, they pressed they spacebar when the clock indicated 11:18 and said: "have a snack". In such a way the tasks were more realistic and the different types of errors possible to be committed by our participants (forgetting that there was something to do at a given moment and forgetting the content of this action) was recorded.

The three videos differed for the PM demand:

Video 1 "*Standard condition*" (Fig. 1A) in which the content of the event-based activity was conceptually connected with the PM cue (i.e., send a letter at the post office) and the time-based activity occurred every 5 min (Fig. 1A). This condition was used as a baseline condition and it was similar to most PM tasks in which the event-based and time-based demands are equivalent in level of difficulty and occur with similar regularity.

Video 2 "*Event-based-HD*" (high-demand) in which the content of the event-based activity did not match with the PM cue (i.e., buy cigarettes at the vet), and the time-based activity occurred every 5 min (Fig. 1B). In this condition, we manipulated the event-based condition and maintained the demand for the time-based activity.

Video 3 "*Time-based-HD*" (high demand) in which the content of the event-based activity was conceptually connected with the PM cue (i.e., have a coffee at the bar) but, and differently from the standard condition, the time-based activity occurred at irregular time-points (i.e., after 2 or 4 min or at 11:03 or 11:18; Fig. 1C) this was done to reduce the regularity of time-based PM actions.

[1] Three independent judges scored the videos for content difficulties and pleasantness and all audio were equivalent.

Procedure

All participants were tested in quiet rooms and particular attention was focused on removing clocks from participants and walls. All PM tasks were performed on a 15-inch PC monitor and participants were seated at a distance of approximately 60 cm from the screen. All participants took part in a single experimental session lasting about 90 min. A short break between PM tasks was allowed. The study was approved by the local ethics committee and also conducted according to the guidelines of the Declaration of Helsinki. The experimental protocol was carefully explained to each participant and written informed consent was obtained from all of them.

Results

Ongoing performance

N-back PM task The numbers of correct 2-back task responses were included into a repeated measures ANOVA with *Group* (young vs. older adults) as between-subjects factor and *PM cue* (Event- vs. Time-based) as within-subjects factor. All significant effects were followed by post-hoc analyses performed with a Holm correction to reduce Type I error rate, and the effect size estimated with partial eta squared (η2p).

A main effect of *Group* [$F(1,38) = 15.48$, $p < .001$, $\eta^2_p = 0.29$; Young $M = 38.97$ (1.68); Older $M = 34.25$ (5.44)] was found indicating that the younger outperformed older participants. No main effect of PM cue nor the interaction was found significant (all $ps \geq 0.0.51$; all $\eta^2_p \leq 0.10$).

Padua PM task The mean number of correct answers at the questionnaires were included into a repeated measures ANOVA with *Group* (young vs. older adults) as between-subjects factor and *PM condition* (Standard, Event-based-HD and Time-based-HD) as within-subjects factor. No main effects of *Group* ($p = .146$, $\eta^2_p = 0.05$) or *PM condition*

($p = .568$, $\eta^2_p = 0.01$), as well as no interaction ($p = .620$, $\eta^2_p = 0.01$) were found.

PM accuracy

In order to compare the performance across the tasks, we used the proportion percent correct scores (dependent variables) and ran a repeated measure ANOVA with *Group* (young vs. older adults) as between-subjects factor and *PM task* (*n*-back, Padua PM Standard, Padua PM Event-based-HD and Padua PM Time-based-HD conditions) and *PM cue* (Event- vs. Time-based) as within-subject factors. Main effects of *Group* [$F(1,38) = 33.93$, $p < .001$, $\eta^2_p = 0.47$; Young: $M = 93\%$ (12%); Older adults: $M = 76\%$ (18%)], *PM task* [$F(1,38) = 18.57$, $p < .001$, $\eta^2_p = 0.33$; *n*-back: $M = 72\%$ (23%); Padua PM Standard :$M = 88\%$ (12%); Padua PM Event-based HD: $M = 88\%$ (14%) and Padua PM Time-based HD: $M = 90\%$ (12%)] and *PM cue* [$F(1,38) = 35.72$, $p < .001$, $\eta^2_p = 0.48$; Event-based: $M = 89\%$ (14%); Time-based: $M = 80\%$ (16%)] were found, indicating that young adults outperformed older ones, participants were less accurate performing the *n*-back task compared to the Padua PM task and participants were more accurate performing the task in the event-based compared to the time-based condition. The interactions (1) *Group* × *PM cue* [$F(1,38) = 7.18$, $p < .008$, $\eta^2_p = 0.17$] and (2) *PM condition* × *PM task* [$F(3,114) = 42.18$, $p < .001$, $\eta^2_p = 0.53$] were significant. Post-hoc analyses showed that (1) older adults were less accurate than younger independently of the type of cue; also, older adults were less accurate when the cue was time-based compared to event-based, while younger participants were equally accurate when the cue was event- or time-based. Moreover, (2) participants were less accurate when the cue was time-based compared to event-based in the *n*-back task, but no differences between type of cue was observed in the Padua PM task; when the cue was event-based no differences between tasks were observed, while significant differences were observed between *n*-back and Padua PM tasks when the cue was time-based.

The interaction *Group* × *PM task* × *PM cue* resulted significant [$F(3,114) = 12.78$, $p < .001$, $\eta^2_p = 0.25$] (Fig. 2). Post-hoc analyses indicated that younger participants were more accurate than older ones in all tasks (all ps < 0.001; all $\eta^2_p > 0.19$) except performing the *n*-back when the PM cue was event-based ($p = .841$, $\eta^2_p = 0.01$) and in the Padua PM Time-based HD when the cue was time-based ($p = .069$, $\eta^2_p = 0.08$) in these conditions the two groups were equally accurate. Within younger group, no differences between tasks were observed when the cue was event-based (all ps < 0.734; all $\eta^2_p > 0.03$), while significant differences were observed when the cue was time-based between *n*-back and Padua PM Standard ($p = .020$) and *n*-back and Padua PM Event-based HD ($p = .010$), indicating higher accuracy performing the Padua PM task compared to the *n*-back tack, also no differences were observed between *n*-back and Padua PM Time-based HD ($p = .079$). Also, younger participants were less accurate performing the *n*-back task when the cue was time-based compared to event-based ($p = .025$); no differences between cues were observed for younger participants in the Padua PM tasks ($p > .304$).

Within older adults, no significant differences were observed when the cue was event-based between tasks; when the cue was time-based significant differences were observed between the *n*-back and all Padua PM tasks (all ps < 0.001). Older adults were less accurate when the cue was time-based compared to event-based performing the *n*-back task ($p < .001$), but they were less accurate when the cue was event-based than time based performing the Padua PM Event-based HD ($p = .044$) and Padua PM Time-based HD ($p = .021$). No difference was observed between cues in the Padua PM Standard task ($p = .738$).

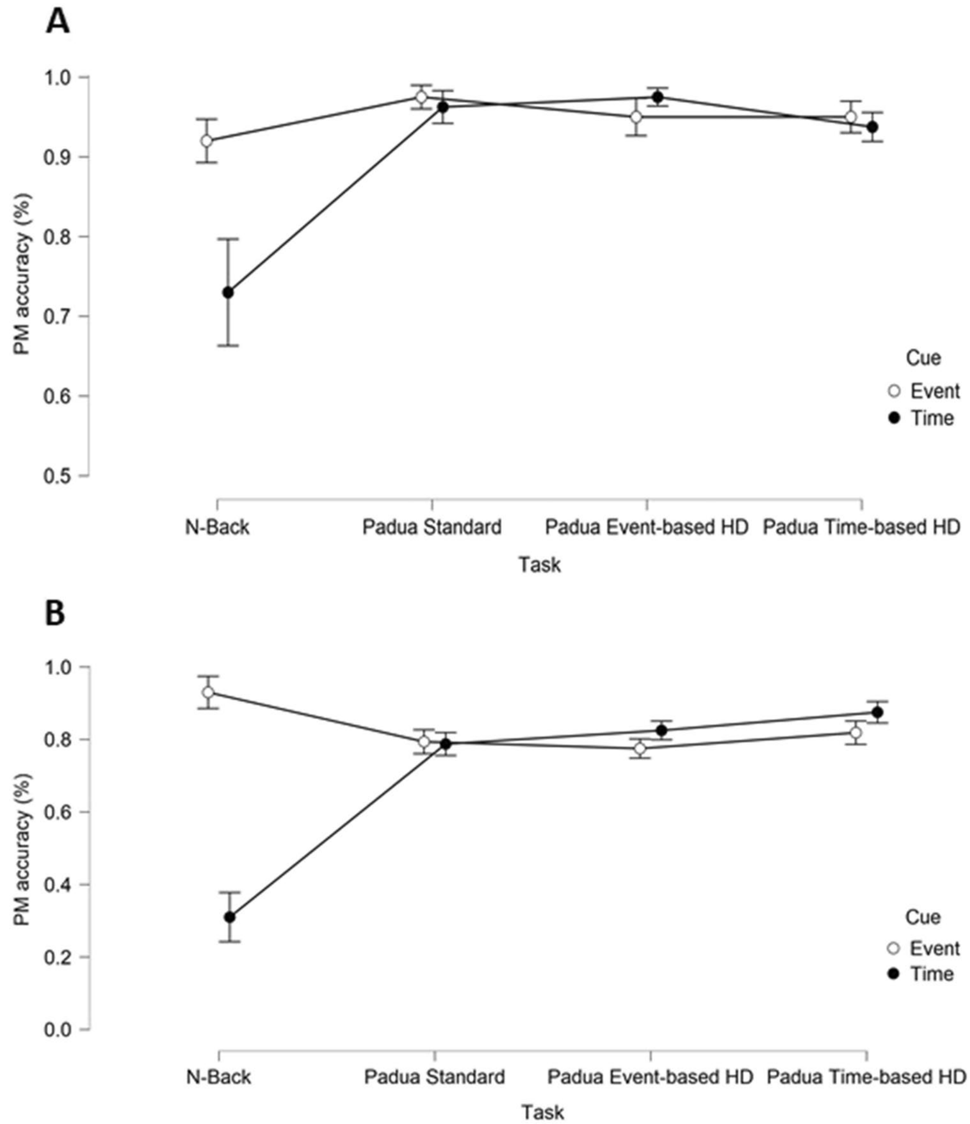
List checking (the Padua PM task) None of the younger participants checked the list while older adults checked the list on average 1.20 (1.44) times in the Standard condition, 1.75 (1.94) times in the Event-based-HD and 1.60 (1.64) times in the Time-based-HD condition. Repeated measures ANOVA were conducted only for older adults for the three conditions as within-subjects factor indicating no significant difference between the three conditions for the number of list checking [$F(1,38) = 2.00$, $p = .150$, $\eta^2_p = 0.10$].

PM accuracy controlling for list checking To further analyse PM performance considering the strategies used by older participants to perform the task, we run new analyses considering the number of times older participants checked the list of PM activities as covariate separately for the Standard, Event-based-HD and Time-based-HD conditions. Three separate ANCOVAs were conducted only for older adult sample with *PM task* (Event- vs. Time-based) as within-subjects factor and *List checking* as covariate.

Standard condition No main effects of *PM task* ($p = .515$ $\eta^2_p = 0.02$), *List checking* ($p = .926$, $\eta^2_p = 0.04$) nor interaction between the two variables ($p = .196$, $\eta^2_p = 0.09$) were found.

Event-based-HD condition We observed a main effect of *PM task* [$F(1,18) = 4.715$, $p = .044$, $\eta^2_p = 0.21$] indicating lower performance when the cue was event-based compared to time-based. Also, the interaction *PM task* × *List checking* [$F(1,18) = 6.241$, $p = .022$, $\eta^2_p = 0.26$]. Indicating that participants that checked the list of PM activities more often were also those more accurate.

Fig. 2 PM accuracy(%). PM performance of **A** younger and **B** older adults at *n*-back and Padua PM -Padua Standard, Padua Event-based-HD and Padua Time-based-HD- tasks, as a function of *PM cue* (Event- vs. Time-based). Error bars indicate standard errors



Time-based-HD condition No main effects of *PM task* ($p = .349$ $\eta^2_p = 0.05$), *List checking* ($p = .238$, $\eta^2_p = 0.08$) nor interaction between the two variables ($p = .238$, $\eta^2_p = 0.08$) were found.

Discussion

The present work aimed to further investigate age-related PM differences between young and older adults comparing a classical laboratory paradigm the *n-back PM task* (Kliegel & Jäger, 2006) with a new high-quality video-based PM assessment namely the *Padua PM task*.

The advantage of using a video-based assessment stands in the opportunity to maintain the rigour and accuracy of laboratory settings but using more naturalistic scenarios, which are more familiar and engaging for older participants compared to classical laboratory PM paradigms. By comparing laboratory based (*n*-back PM task) and a video-based PM assessment (Padua PM task) we were able to further investigate age-related PM performance. Also, we were interested in understanding the different processes involved in the retrieval of intentions, to pursue this aim we manipulated the difficulties on both event and time-based tasks by defining three different conditions for the Padua PM task namely "*Standard condition*", "*Event-based High Demand*" (HD) and "*Time-based High Demand*" (HD). Introducing three different conditions we could disentangle age-related PM differences in event and time-based tasks also as a function of cognitive demand. More precisely, we manipulated the demands of the cue-action association in the event-based condition and the time regularity in the time-based condition.

The results of *n*-back PM task showed that older adults were less accurate than younger participants performing the ongoing task, but no effect of PM task (event or time-based condition) was observed on participants' ongoing performance. Age-related changes –in favour of young adults' advantage– were reported in several studies using *n*-back tasks (Bopp & Verhaeghen, 2018); the lack of differences in ongoing task performance depending on PM condition (event or time-based condition) might suggest that participants allocated attentional resources to the *n*-back task similarly in both PM task conditions. However, considering the PM task accuracy, this resource allocation appeared differently efficient. The results of PM performance of the *n*-back PM task confirmed lower accuracy in older participants when the PM cue was time-based PM compared to event-based. These results confirmed previous findings indicating that time-based activities require more self-initiated monitoring processes to be completed and that time-based tasks benefit less from environmental support as observed in event-based PM tasks (Jäger & Kliegel, 2008).

Considering the ongoing performance of the Padua PM task, we found similar performance in younger and older adults, this result does not confirm the group effect observed during the *n*-back task. It is important to note that the two ongoing tasks required different level of cognitive load. Indeed, previous studies that manipulated the difficulties of the ongoing task highlighted that older adults are less accurate than younger in high cognitive load compared to low cognitive load conditions (Einstein et al., 1997; d'Ydewalle et al., 2001; Kidder et al., 1997; Logie et al., 2004; Mäntylä et al., 2009; van der Berg et al., 2004).

Considering PM performance, in line with the literature (Jäger & Kliegel, 2008; Mioni et al., 2019), we confirmed lower PM performance in older adults compared to younger adults and lower PM performance in the time-based compared to the event-based PM tasks.

Concerning our first aim to compare a computerised and naturalistic video PM task we observed that in both cases younger participants outperformed older participants, which is in line with widely reported age differences in laboratory tasks (e.g., Henry et al., 2004; Ihle et al., 2013; Kliegel et al., 2008). Consistent with previous studies that used laboratory tasks, older adults showed lower performance when the PM cue was time-based compared to event-based in the *n*-back PM task (Brandimonte et al., 2014), this result was not confirmed in the Standard condition of the Padua PM task.

More interesting for the present study, are the results concerning the performances during Event-based-HD and Time-based-HD conditions of the Padua PM task. For the first time, at least to our knowledge, such a manipulation, to further investigate age-related PM performance differences and the influence of varying -attentional and retrieval- demands on performance, was introduced. For the time-based HD condition, the target times were irregular time points during the video, whereas for the event-based HD condition the association between the PM cue and the intended action was low imposing higher strategic demands to retrieve the correct task. In both HD conditions, participants would need to engage in more attentional monitoring to detect the PM cues or the target times, respectively to successfully retrieve the PM intention compared to the standard condition (e.g., McDaniel & Einstein, 2000). Interestingly, we did find reduced performance in older adults in event-based compared to time-based tasks in the event-based and time-based HD conditions. This indicated that the more demanding event-based PM activities using a low association between PM cue and intended action imposed higher strategic search processes for the task than the time-based tasks. It suggests that time-based tasks are not necessarily more attentionally demanding or difficult than event-based tasks, but that the involvement of more or less attentional resources, related to the degree of the cue-action association, seems to influence performance differences in different task types. Also, we did not find a difference for the more demanding time-based condition compared to the standard event-based condition further supporting the conclusion that it is not the task type per se, but the involvement of other processes like attention allocation and low cue-action association could explain performance differences. The Padua PM task and its manipulation of task demands seems to be a useful addition to existing paradigms in disentangling resource allocation processes, especially in event-based tasks.

A critical and new aspect of the Padua PM task was also the possibility to register the number of time participants checked the list of PM tasks as reminder. This was introduced also to further study the strategies used by participants during the PM tasks. Interestingly, and differently from older adults, none of the younger participants checked the list. However, older adults checked the list to a similar extent in the standard and high demand conditions. It suggests that older adults did not rely on their PM encoding ability, even for the easier version. There are several possible reasons that could explain the list checking. One possible interpretation relates to older adults' awareness of their memory difficulties; older adults have, in fact, been found to use memory-aiding strategies to a greater extent than younger adults to compensate for their memory difficulties, particularly in the more complex and resource consuming situations (Bouazzaoui et al., 2010). Older adults could thus try to compensate for potential forgetting by relying on this external list checking strategy. Also, they might have been more motivated to perform well in the task using all options to maximize their performance. By introducing the number of list checks as covariate, we observed that older adults who checked the list more often were also more accurate in their PM performance, however, this was only the case for the HD event-based condition. In conclusion, this pattern shows that older adults used the strategy of list checking independently of the task demands, but this compensatory behaviour was only beneficial in the HD event-based task condition, where the association between PM cue and intended action was lower than in the standard condition imposing also higher demands on encoding of the PM activities. For future studies, it would be interesting to investigate whether external aids or strategies could similarly benefit time-based PM as well. Moreover, it is important to note that participants could read and memorise the list of PM tasks for 3 min before starting with the task. Based on previous studies using the Virtual Week board game (Mioni et al., 2015, 2017), 3 min can be considered a reasonable time for all participants to read the list of to-be-remembered activities and familiarise with them and the experimenter was always present during this encoding phase in case of need. Future studies should make the effort to address the encoding time more specifically in order to confirm the present results. It is worth mentioning the accuracy reached by the two groups -and independent of the conditions-, along with the frequency of the checking the list -none of the younger participants checked the list and ¼ of older participants did not check the list at all- can be indirect measures of the adequacy of the encoding time selected. None of the participants, then, reported difficulties related to the encoding time.

The Padua PM task seems to be a useful tool to investigate age-related differences in PM performance in the laboratory while using naturalistic task material. The ongoing task did not show age differences, whereas they were found for the PM task indicating that the ongoing activity was engaging for both age groups, but not disadvantaging one group over the other. However, there are some limitations to consider when applying the new paradigm. We did not find a difference between the two time-based PM conditions suggesting that the regularity manipulation of the time-based activities would need further calibration to be more sensitive. The idea was to make it less regular, which would make the cue-action association more demanding (less habitual times) (Rose et al., 2015). One possibility would be to let participants press another button to check the time or to use an external clock outside of the video. This would also allow to assess time monitoring in a similar way as list checking and to compare both strategies in future studies.

A limitation of the present study comes from the sample size. We acknowledge that the two groups are quite small, but we believe that our study can still provide interesting insights into the understanding of age-related PM reduction in particular considering the debate of assessing PM performance with laboratory or more ecological measures. Also, it is important to note that our older adults were relatively young (mean age = 68.90 years; SD = 3.46) and they have a high level of education (older adults = 17.40 years of education) compared with previous studies investigating PM in aging. This might have mitigated age-related PM differences.

It is also important to mention a methodological difference between the *n*-back and the Padua PM task concerning the time-based implementation. The clock was hidden in the *n*-back task, while it was always displayed for the Padua PM Task. This might have created a constant reminder for the time-based tasks and may have made time-based PM tasks more salient than event-based tasks in the Padua PM task. Future studies using the Padua PM task should be conducted hiding the clock (see Mioni et al., 2020), in order to control for its role and replicate the present results. However, it is to note that in the present study, the clock was positioned at the down-right corner of the computer screen, which can be considered a side position compared to the centre of the screen. Further, when creating the Padua PM task, we have adopted a procedure similar to the one used with Virtual Week task (Rendell & Craik, 2000) where the virtual clock is always displayed at the centre of the board and the stop-clock is also constantly visible above the virtual clock. Results using Virtual Week provide evidence that, despite the clock being visible at the centre of the board, participants were less accurate performing the time-based compared to the event-based PM activities (Rendell & Henry, 2009 for a review of studies). Finally, a further version of the Padua PM task should also include a forth video including both Event-based HD and Time-based HD conditions within the same video.

In conclusion, the Padua PM tasks seem to offer a new and original tool to assess PM performance with a naturalistic task in controlled laboratory setting. The Padua PM task seems to be sensitive to detect age differences in PM between younger and older adults with the advantage of the type of naturalistic engaging and more real-world oriented paradigm along with the possibility to investigate attentional and retrieval processes underlying age-differences.

Acknowledgements This work was carried out within the scope of the project "use-inspired basic research", for which the Department of General Psychology of the University of Padova has been recognized as "Dipartimento di Eccellenza" by the Ministry of University and Research.

Funding This research was supported by Visiting Programme (2018), Fondazione Cassa di Risparmio di Padova e Rovigo.

Data availability The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Conflict of interest There are no relationships that could be interpreted as a conflict of interest affecting this manuscript.

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