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# Using mental visual imagery to improve autobiographical memory and episodic future thinking in relapsing-remitting multiple sclerosis patients: A randomised-controlled trial study

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## Abstract.

**Purpose:** The co-occurrence of autobiographical memory (AM) and episodic future thinking (EFT) impairment has been documented in relapsing-remitting multiple sclerosis (RR-MS) patients. On these bases, we aimed at probing the efficacy of a mental visual imagery (MVI)-based facilitation programme on AM and EFT functioning in the context of a randomised-controlled trial study in RR-MS patients.

**Methods:** Using the Autobiographical Interview (AI), 40 patients presenting with an AM/EFT impairment were randomly assigned in three groups: (i) the experimental ( $n = 17$ ), who followed the MVI programme, (ii) the verbal control ( $n = 10$ ), who followed a sham verbal programme, and (iii) the stability groups ( $n = 13$ ), who underwent the AM/EFT test twice, with no intervention in between.

**Results:** AI's second assessment scores showed a significant improvement of AM and EFT performance only for the experimental group, with a long-term robustness of treatment benefits.

**Conclusions:** The control and stability groups' results ruled out nursing and test learning effects as explanations of AM/EFT improvement. These benefits were corroborated by the patients' comments, which indicated an effective MVI strategy transfer to daily life. Our results suggest that the MVI programme tackles a common cognitive process of scene construction present in AM and EFT.

**Keywords:** Autobiographical memory, episodic future thinking, neuropsychological rehabilitation, mental visual imagery, multiple sclerosis

## 1. Introduction

The experience of brain injury leads to major disruptions in every domain of an individual's life and

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34 provokes, more often than not, significant changes  
35 in how a person interprets his/herself and the world  
36 around (Gracey et al., 2008). In this context, clinicians  
37 are now aware that neuropsychological interventions  
38 need to address cognitive, emotional, psychosocial  
39 and behavioural problems resulting from brain injury  
40 and that cognitive impairment should not be isolated  
41 from other factors (Wilson & Gracey, 2009). In this  
42 perspective, the transfer of benefits resulting from  
43 neuropsychological interventions to everyday life is  
44 considered as the core of “successful cognitive reha-  
45 bilitation” (Wilson, 1987, 2008).

46 In the broad spectrum of cognitive dysfunction,  
47 memory impairment is one of the most frequent issues  
48 following brain injury. Its frequency and the fact that  
49 memory disorders compromise patients’ ability to par-  
50 ticipate in daily life activities have probably contributed  
51 to the development of several compensatory interven-  
52 tions (Evans, 2009). While the great majority of studies  
53 focused on the improvement of anterograde memory,  
54 more recently, a growing interest for the development of  
55 therapeutic interventions to improve autobiographical  
56 memory (AM) has been observed. Briefly stated, AM  
57 corresponds to the ability to mentally re-experience per-  
58 sonal detailed events, within a specific spatio-temporal  
59 context, as they are remembered (Tulving, 2002). Sev-  
60 eral functions have been attributed to AM, such as its  
61 role in the construction of sense of self temporally  
62 extended, the development of new social relationships  
63 and the nurturing of existing ones, and a directive func-  
64 tion where the past serves as a basis to guide present  
65 and future behaviours (Rasmussen & Habermas, 2011).  
66 Taken together, AM constitutes a central process in any  
67 individual’s life and, not surprisingly, could be seen  
68 as the reason of the endeavour to improve its func-  
69 tioning. To our knowledge, two lines of research have  
70 been explored so far to improve AM functioning in  
71 patients and have led to positive outcomes: using an  
72 external device such as the SenseCam (e.g. Berry et al.,  
73 2007; Loveday & Conway, 2011; Pauly-Takacs et al.,  
74 2011; Woodberry et al., 2015) and applying training  
75 programmes (Raes et al., 2009; Neshat-Doost et al.,  
76 2013; Moradi et al., 2014). Overall, it appears that train-  
77 ing programmes are applied in psychiatric diseases,  
78 whereas external devices are mostly used in neurologi-  
79 cal conditions presenting with severe AM impairment.  
80 In the context of mild-to-moderate AM disorder, Ernst  
81 et al. developed a facilitation programme (created by  
82 one of us LM; see Ernst et al., 2012, 2013) based on  
83 the critical role of mental visual imagery (MVI) in

AM retrieval and vividness of memories (Greenberg &  
Rubin, 2003). The MVI programme was specifically  
designed to improve AM impairment in relapsing-  
remitting multiple sclerosis (RR-MS) patients, for  
which a prefrontal dysfunction origin was suggested.  
AM impairment in RR-MS patients has been found to be  
frequent, even in patients presenting with a preservation  
of their general cognitive functioning, with a deleteri-  
ous impact of this impairment in patients’ daily life  
(Ernst et al., 2014a). The MVI programme stemmed  
from this initial clinical observation. This tailor-made  
facilitation programme was built to alleviate executive  
function-related AM impairment in RR-MS patients,  
in the context of, at most, mild cognitive impairment  
in other cognitive functions, and with the use of an  
integrated cognitive strategy transferable to daily life  
functioning. Benefits of this programme on AM func-  
tioning were reported, with a high rate of individual  
improvement and with an effective transfer of treatment  
benefits in daily life functioning. Nevertheless, beyond  
the small sample size, some limitations restricted the  
conclusions drawn from these previous studies, includ-  
ing the absence of a patients’ control group or follow-up  
measures of the robustness of treatment effects.

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108 Recently, based on the theoretical framework of men-  
109 tal time travel (Suddendorf & Corballis, 1997; Tulving,  
110 2001, 2002), Ernst and co-workers extended their find-  
111 ings of AM impairment in RR-MS patients to Episodic  
112 Future Thinking (EFT; Ernst et al., 2014a). Similarly  
113 to its past counterpart, EFT enables people to men-  
114 tally simulate personal detailed events within a specific  
115 spatio-temporal context. More specific to EFT, it con-  
116 tributes to coping skills, goal achievement, intention’s  
117 implementation or to the sense of personal continuity  
118 overtime (Szpunar, 2010; D’Argembeau et al., 2012).  
119 In the case of RR-MS patients, AM and EFT impair-  
120 ment seemed to coexist and deficits in the two temporal  
121 directions were highly interrelated. This finding was  
122 consistent with the mental time travel literature, which  
123 posits that AM and EFT share striking similarities at  
124 both cognitive and neural levels (see Schacter et al.,  
125 2012 for a review). In both cases, a main role of exec-  
126 utive functions was put forward to explain AM and EFT  
127 impairment in MS patients, with compromised retrieval  
128 strategies, as well as difficulties to extract and recombine  
129 details to form personal memories and mental simula-  
130 tions. Importantly, the AM and EFT difficulties were  
131 amply corroborated by the patients’ reports, who com-  
132 mented on the negative impact of this deficit in their daily  
133 life functioning.

Using the same MVI facilitation programme than in previous works (Ernst et al., 2012, 2013), we sought to investigate, in the context of a randomised-controlled trial (RCT) design to what extent AM and EFT could be jointly improved in RR-MS patients. Considering the theoretical (Tulving, 1985; see Schacter et al., 2012 for a review) and empirical (Addis et al., 2009; D'Argembeau et al., 2004, 2008) relationships between AM and EFT, we hypothesised that significant improvement would be observed in both temporal directions. Finally, we hypothesised that any benefits gained thanks to our facilitation programme would show long-term preservation.

## 2. Material and methods

### 2.2. Participants

Sixty-two RR-MS patients (following Polman et al.'s, 2011 diagnosis criteria) were recruited, with an Expanded Disability Status Scale (EDSS; Kurtzke, 1983) score  $\leq 5$  and no recent exacerbation of MS symptoms. Only patients presenting with a RR-MS disease course were recruited and the absence of progression between relapses has been verified through clinical follow-up. Patients were seen on a monthly basis at the day-care hospital in the context of their treatment administration (Tysabri<sup>®</sup>, natalizumab) and on a yearly basis to reassess disease course by means of clinical and MRI examinations.

Only MS patients with impaired AM and EFT performance, in the context of mild to moderate cognitive impairment in attention and/or executive functions and in the absence of major anterograde memory deficit, were included in the present study. Moreover, an absence of major signs of depression according to the Montgomery and Asberg Depression Rating Scale

(Montgomery & Asberg, 1979; score  $\leq 15$ ) had to be observed. These additional inclusion criteria were set to control the presence of confounding factors on AM/EFT performance and to guarantee the further good completion of the facilitation programme. After this selection, 40 RR-MS patients were finally included in the study, randomly assigned in three groups: the experimental, the verbal control and the stability groups (see the Procedure section for further details).

Demographic and clinical data are summarised in Table 1. The present study was approved by the 'Committee for Protection of Persons' (CPP/CNRS N<sup>o</sup> 07023) and we complied with the Declaration of Helsinki.

### 2.2. Structural neuroimaging data

To obtain descriptive data on the MRI abnormalities presented by the current group of MS patients, brain regions showing significant signs of atrophy have been explored before facilitation.

MRI examinations were performed on a 3T MRI scanner (MAGNETOM Verio, Siemens Healthcare, Erlangen, Germany). Structural images were obtained by means of a 3D T1-weighted SPACE (Sampling Perfection with Application optimized Contrasts using different flip angle Evolution) sequence (TR = 4000 ms, TI = 380 ms, TE = 383 ms, flip angle = 120°, FOV = 256 mm, matrix = 512 × 512, 176 sagittal slices of 1 mm). 3D T2 Fast Spin Echo images were also acquired with the following parameters: TR = 3200 ms, TE = 409 ms, flip angle = 120°, FOV = 256 mm, matrix = 512 × 512, 176 sagittal slices of 1 mm.

Focal grey matter (GM) atrophy was investigated using the Voxel Based-Morphometry (VBM) framework provided in SPM12b (Statistical Parametric Mapping, <http://www.fil.ion.ucl.ac.uk/spm/>).

Table 1  
Demographic and clinical data: mean (and standard deviation) for the three groups of patients

	MS patient groups			Statistical analysis
	Experimental (n = 17)	Verbal control (n = 10)	Stability (n = 13)	
Age (in years)	42.00 (10.37)	37.40 (8.85)	40.00 (3.85)	$F(2, 37) = 0.95, p = 0.39$
Education (in years)	13.29 (2.17)	12.20 (1.55)	13.77 (2.45)	$F(2, 37) = 1.56, p = 0.22$
Sex ratio (female/male)	13/4	9/1	9/4	$\chi^2 = 1.41; p = 0.49$
EDSS	2.68 (1.58)	2.45 (1.40)	2.77 (1.41)	$F(2, 37) = 0.13, p = 0.87$
Duration of MS (in years)	10.97 (9.53)	10.60 (5.66)	11.85 (7.01)	$F(2, 37) = 0.07, p = 0.92$
Number of DMD treatment	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	-

DMD = Disease Modifying Drug.

204 Anatomical MRI images were spatially pre-processed  
205 in the following way: all T1 structural images were bias  
206 corrected, segmented using an extension of the unified  
207 segmentation procedure (Ashburner & Friston, 2005)  
208 that includes six classes of tissue. Spatial normalisa-  
209 tion was then performed using DARTEL algorithm  
210 (Ashburner, 2007). First, a study-specific template was  
211 created using GM images of all subjects. Second, this  
212 template was normalised to Montreal Neurological  
213 Institute space. Third, the individual deformation field  
214 that permits to normalise each GM image to the tem-  
215 plate was computed and applied to each GM image and  
216 modulated to preserve the total amount of GM volume.  
217 A Gaussian kernel (FWHM: 8 mm) was then applied  
218 to modulated GM images and entered in the statistical  
219 analysis.

220 Group comparison on local GM volume was investi-  
221 gated using the General Linear Model and with a group  
222 of 18 healthy controls matched for age, gender and  
223 education involved in our previous study (Ernst et al.,  
224 2014b). Age and total amount of GM were included as  
225 nuisance covariates in all statistical analyses. A statisti-  
226 cal threshold of  $p < 0.001$  without multiple comparison  
227 correction and with a cluster spatial extend of  $k = 100$   
228 voxels was considered in all analyses.

### 229 2.3. Neuropsychological examination

230 A comprehensive neuropsychological baseline was  
231 administered to the MS patients in a first session.  
232 General verbal abilities were tested with a short form  
233 (Axelrod et al., 2011) of the Verbal IQ of the WAIS-  
234 III (Wechsler, 1997) and nonverbal reasoning was  
235 assessed using the Advanced Progressive Matrices Set  
236 1 (Raven, 1958). Anterograde memory was examined  
237 with the Rey auditory verbal learning test (RAVLT;  
238 Rey, 1964), and the Rey-Osterrieth Complex Figure  
239 (ROCF; Rey, 1941; Osterrieth, 1944). The executive  
240 functions were probed by means of the phonological  
241 and categorical fluency tests (National Hospital, Lon-  
242 don), the Brixton Spatial Anticipation test (Burgess  
243 & Shallice, 1997), the Tower of London (Shallice,  
244 1982), and the Cognitive Estimation Task (Shallice &  
245 Evans, 1978). The attentional abilities and information  
246 processing were assessed using the Information Pro-  
247 cessing Speed test from the Adult Memory Information  
248 Processing Battery (AMIPB; Coughlan & Hollows,  
249 1985), the Stroop test (Stroop, 1935), and the months  
250 backwards test (National Hospital, London). Language  
251 was tested with the Déno 100 test (Kremin, 2002), and

the visuo-perceptual and visuo-spatial abilities with  
the Silhouettes and Cube Analysis sub-tests from the  
Visual Object and Space Perception Battery (VOSP;  
Warrington & James, 1991). In addition, the impact of  
fatigue in everyday life was assessed using the 'Echelle  
de Mesure de l'Impact de la Fatigue' (EMIF-SEP;  
Debouverie et al., 2007).

### 259 2.4. AM and EFT assessment

260 In a second session, AM/EFT performance was  
261 assessed by means of an adapted version of the Auto-  
262 biographical Interview (AI; Levine et al., 2002; Addis  
263 et al., 2009). MS patients and healthy controls were  
264 instructed to retrieve/imagine personal unique events,  
265 temporally and contextually specific, occurring over  
266 minutes to hours (but no longer than one day) and to  
267 freely generate as much details as possible about the  
268 event. Regarding the AM condition, three past events  
269 per life period were collected [i.e. four or five life peri-  
270 ods, depending on the subject's age; 0–11 years, 12–20  
271 years, 21 to (current age – 1) or 21–35 years, 36 to  
272 (current age – 1) and the previous year]. For the EFT  
273 component, subjects had to generate five future events  
274 that could plausibly occur within the next year. Partici-  
275 pants were informed that the cue-words were intended  
276 to be used flexibly and no time limit was set to avoid the  
277 potential influence of patients' slowed down cognitive  
278 processing speed on AM/EFT performance. General  
279 probes (e.g. "is there anything else you can tell me?")  
280 were used to clarify instructions if necessary and to  
281 encourage evocation of additional details.

282 The AI session was audio-recorded for later tran-  
283 scription and scored following the Levine et al.'s  
284 standardised procedure: after the identification of the  
285 central episodic event, details were classified as inter-  
286 nal details (i.e., an episodic detail related to the central  
287 event) or external (i.e., non-episodic information such as  
288 semantic details, metacognitive statements, repetitions  
289 or episodic details unrelated to the central event). A qual-  
290 itative assessment of the episodic re-/pre-experiencing  
291 was also provided by ratings for episodic richness, time,  
292 space, perception and emotion/thought composites for  
293 each memory. The free recall and the general probe  
294 phases were analysed as a whole, considering the minimal  
295 influence of this last one on recall (Levine et al.,  
296 2002). For each participant, the number of internal and  
297 external details, as well as the mean rating score were  
298 averaged across the 12 or 15 past events, and across the  
299 five future events for the EFT condition.

300 Following Levine et al.'s (2002) procedure, the inter-  
301 rater reliability was verified for 10% of the past and  
302 future events, which were scored by a second scorer,  
303 blind of the patient's group allocation and study phase  
304 (pre- or post-facilitation). Coefficients for all measures  
305 showed high interrater reliability (between 0.82 and  
306 0.99).

307 In order to characterise the potential impact of  
308 AM/EFT difficulties and the perceived benefit of the  
309 facilitation programme in MS patients' daily life func-  
310 tioning, a semi-structured interview was conducted  
311 at the end of each AI session. This semi-structured  
312 interview was similar to the one used by Ernst and  
313 colleagues (2014a) and encompassed four dimensions:  
314 vividness, accessibility, sensory details and emotional  
315 intensity of personal past and future events. Consid-  
316 ering the broad range of everyday life situations in  
317 which AM and EFT abilities are involved, a semi-  
318 structured interview was deemed to be better adapted  
319 than a questionnaire to explore changes in real life.

## 320 2.5. AM and EFT MVI facilitation programme

321 The MVI programme is based on the ability to men-  
322 tally construct scenes and to pay close attention to  
323 details in the mind's eye. Following a goal directed  
324 approach (Wilson & Gracey, 2009), the first step of the  
325 programme is to carefully explain its aim, content and  
326 how it is supposed to help the memory impairment.  
327 This introduction is important to promote its further  
328 use in daily life. Along these lines, the neuropsycholo-  
329 gist is very attentive to treatment receipt (i.e. the extent  
330 to which the patient understands the strategies or tech-  
331 niques taught, and demonstrates the capacity to use  
332 them; Hart, 2009).

333 The MVI programme encompassed six two-hour  
334 sessions, once or twice per week (depending on the  
335 patient's availability). The programme comprised four  
336 steps, with mental visualisation exercises of increas-  
337 ing difficulty, during which the neuropsychologist  
338 provided a continuous guidance (as much as neces-  
339 sary), probing the patient from general aspects to more  
340 detailed ones, adopting a 'funnel-approach' and learn-  
341 ing to work in a sequential manner. (i) The *screening*  
342 *test* was based on three subtests from the 'Imagery and  
343 Perception Battery' (Bourlon et al., 2009): the 'mental  
344 representation of physical detail', the 'morphological  
345 discrimination' and the 'colour comparison' tests. We  
346 used a shortened version of each test, with normative  
347 data established with a group of 15 healthy controls

(unpublished data). These tests were used to probe  
basic visual imaging abilities, which enabled us to  
exclude the patients, who presented scores below the  
normal range for all the three subtests (and therefore  
incompatible with the implementation of the facil-  
itation programme). (ii) The *external visualisation*  
included 10 verbal items to imagine and describe in  
as many details as possible (e.g. shape, colour, size,  
etc), with the complementary visualisation of an action  
made with the item (e.g. visualise an onion and visu-  
alise it again, once sliced). (iii) The *construction phase*  
consisted in figuring out complex scenes, bringing into  
play several characters and various scenarios. Five ver-  
bal items were proposed for each part of the exercise:  
a first training step (e.g. imagine the hotel of your  
holidays) and a subsequent mental scene construc-  
tion, sharing thematic similarities (e.g. imagine the  
house of your dreams), allowing the patient to rely  
on the training section to construct the next scene.  
(iv) The *self-visualisation* followed the same procedure  
but here, patients were asked to visualise themselves  
within a given scenario, to imagine it as though they  
were actually living the scene, with the description of  
all kind of details, sensations or feelings that came to  
mind. A first training scene was proposed (e.g. imagine  
you take part in a magic show), followed by a second  
scene with a similar theme (e.g. imagine you enter in  
the big cats' cage for a show).

### 376 2.5.1. Verbal control programme

377 Greenberg and Rubin (2003) put forward the role of  
378 narrative structure which enables organisation in AM,  
379 provides temporal and goal structure, with a kind of  
380 scaffold on what has to be included or excluded in a  
381 memory. However, narrative structure plays a minor  
382 role in comparison with MVI in AM. On these bases,  
383 we developed a narrative-oriented control programme  
384 which could plausibly be linked to AM and EFT  
385 performance, with the same number and frequency  
386 of sessions. Narration was also selected because  
387 this cognitive ability is not part of the frequently  
388 described cognitive impairment in MS patients. We  
389 strictly observed the same clinical characteristics and  
390 interactions with patients than the MVI programme.  
391 The programme was presented as one focusing on  
392 the importance of the information organisation, on the  
393 bases of a series of texts extracted and selected from  
394 various websites, covering a wide range of news topics.  
395 After a first reading of the text, the general goal was  
396 to exchange about the topic of the text, introducing

397 different directions through steps of increasing dif- 445  
398 ficulty. A continuous guidance was provided, with 446  
399 supplementary questions to rekindle the dialogue and 447  
400 patients were encouraged to construct a structured talk. 448  
401 This last point enabled the patient to work in a sequen- 449  
402 tial manner, in parallel with the MVI programme. 450

403 Three steps were proposed: (i) *the external discus-* 451  
404 *sion* relied on the identification of influent variables 452  
405 on text understanding related to its form (e.g. clarity, 453  
406 vocabulary used) and comprised 20 texts. This step was 454  
407 very brief and corresponded to the MVI programme 455  
408 external visualisation. (ii) *The discussion construction* 456  
409 comprised five items, with a training and a construc- 457  
410 tion step for each item, with two texts thematically 458  
411 related to enable the reliance on the first to construct 459  
412 the second one (e.g. a first text dealing with a trip to 460  
413 South Africa was followed by a text about a trip to 461  
414 Ireland). (iii) *The self-involved discussion* was simi- 462  
415 lar to the previous step, with the addition of questions 463  
416 about his/her own opinion (e.g. a first text about taxing 464  
417 sodas to reduce their consumption was followed by a 465  
418 second text concerning the usefulness of anti-smoking 466  
419 campaigns). 467

## 420 2.6. Procedure

421 Prior to inclusion, a selection of MS patients was 445  
422 made based on the neuropsychological baseline exami- 446  
423 nation. The aim was to control for the absence of severe 447  
424 cognitive impairment other than AM/EFT deficit. To 448  
425 continue towards the next steps, the patients had to be in 449  
426 the normal range on all tests (threshold: either z-score 450  
427  $-1.65$  or the 5th percentile, depending on normative 451  
428 data), except for attentional and executive functions, 452  
429 for which mild impairment was accepted (defined in 453  
430 this study as a failure to one attentional test and/or two 454  
431 executive function tests, at the most). 455

432 As mentioned above, only MS patients showing 456  
433 AM/EFT impairment were included in this study. The 457  
434 presence of an AM/EFT was based on the AI norma- 458  
435 tive database previously used by Ernst et al. (2012), 459  
436 including the mean number of internal details and the 460  
437 mean total rating obtained during the free recall phase. 461  
438 Indeed, these measures assess the episodic re-/pre- 462  
439 experiencing ability, taking into account the sensitivity 463  
440 of the free recall to detect deficit. Patient's free recall 464  
441 performance were considered to be impaired if the 465  
442 mean score for internal details was  $\leq 22$  and the mean 466  
443 score for total ratings was  $\leq 8$  for the AM condi- 467  
444 tion, and if the mean number of internal details was

445  $\leq 18$  and the mean total rating was  $\leq 7$  for the EFT 446  
447 condition. 448

449 To obtain a reliable assessment of potential AM/EFT 450  
451 performance change, a strictly similar AI procedure 452  
453 was followed at each session. They only differed in 454  
455 the cue-words, which were set up beforehand and 456  
457 randomly assigned across AI sessions. Importantly, 458  
459 if patients evoked past/future events already provided 460  
461 during a previous AI sessions, or events similar to or 462  
463 based on simulations produced during the MVI pro- 464  
465 gramme, patients were asked to find an alternative 466  
467 event. 468

469 The final 40 MS patients were randomly assigned in 470  
471 the three following groups: (i) the experimental group, 472  
473 who followed the MVI facilitation programme; (ii) the 474  
475 verbal control group, who underwent the verbal control 476  
477 programme and aimed to verify the absence of a nurs- 478  
479 ing effect; and (iii) the stability group, whose inclusion 479  
480 was thought to control for learning effects due to 480  
481 repeated AM/EFT assessments. Regarding the stabil- 481  
482 ity group, the second AI assessment was conducted 6 482  
483 to 8 weeks after the first AI assessment to homogenise 483  
484 the time interval between the two assessment sessions 484  
485 in every group. Once this step was completed, the 485  
486 13 patients from the stability group were due to fol- 486  
487 low the MVI programme. However, owing to personal 487  
488 time constrains from the patient ( $n = 2$ ) or MS relapse 488  
489 ( $n = 1$ ), three patients from the stability group dropped 489  
490 out from the study. 490

491 For all MS patients who had followed the MVI pro- 492  
493 gramme, a long-term follow up AI assessment was also 493  
494 completed six months after the initial post-facilitation 494  
495 assessment. This additional session aimed at assessing 495  
496 the maintenance of benefits for patients, and to gather 496  
497 their impressions about the use and impact of the MVI 497  
498 strategy in their daily life. A diagram summarising the 498  
499 study design is presented in Fig. 1. 499

500 Patients were blind to their allocation group and, 501  
502 importantly, they had never before participated in simi- 502  
503 lar studies. The presentation of the study informed the 503  
504 patients of the constitution of different groups of partic- 504  
505 ipants, with two possible interventions, whose efficacy 505  
506 was going to be tested during the study. However, 506  
507 since each patient was followed by the same neuro- 507  
508 psychologist (AE for 78% of patients) during his/her 508  
509 participation (from the baseline examination to the 509  
510 long-term follow-up), the neuropsychologist was not 510  
511 blind to the patient's allocation group. Since in the con- 511  
512 text of a goal directed approach, a blind condition was 512  
513 difficult to set for the neuropsychologist, we designed 513  
514

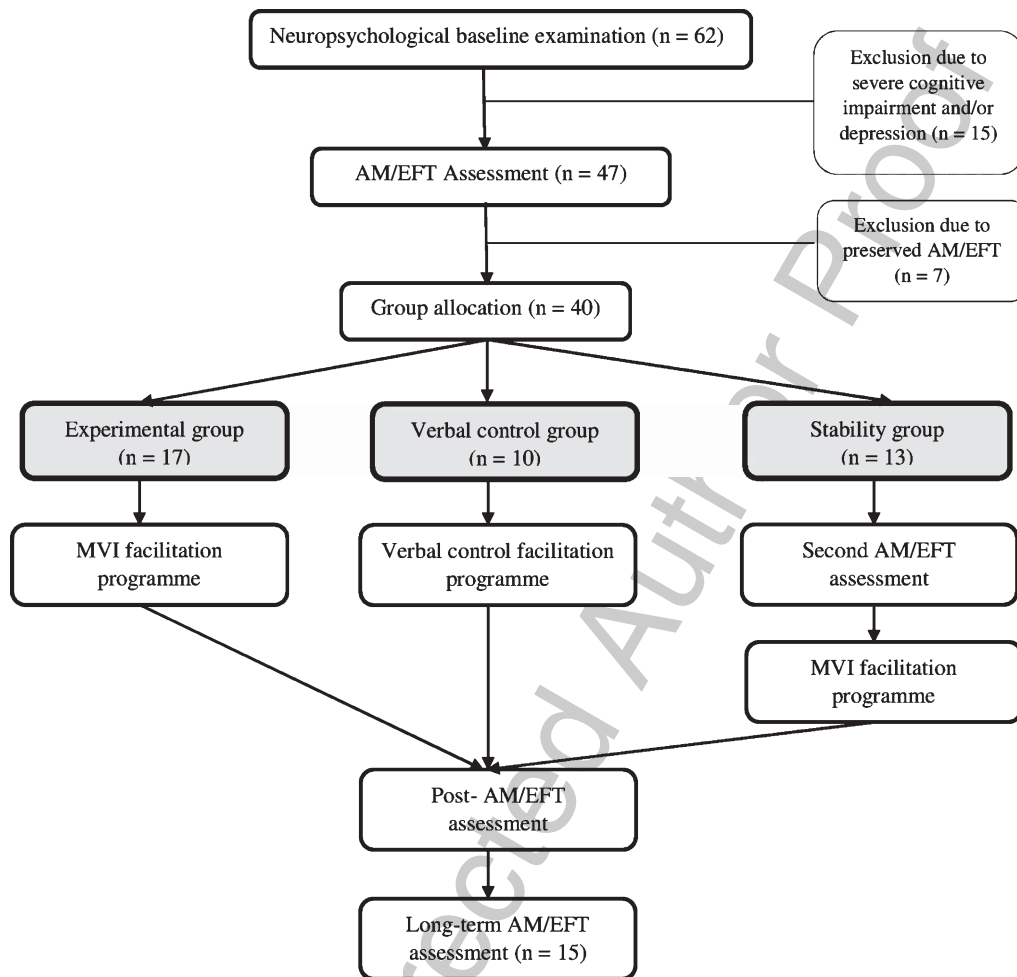


Fig. 1. Study design diagram summarising the group allocation and progression of patients through study phases.

our study in agreement with the recommendations of the Neuropsychological Rehabilitation Consensus Conference (Làdavass et al., 2011). This document acknowledges the potential issues if the investigator is not blind to some aspects of the research. However, to control the potential influence of the investigator's awareness of the patient's group allocation, the second AI scorer was blind to the group membership, in every case. Moreover, AI reports were anonymised, personal past and future events were not supplied for scoring in the chronological order of assessment (i.e., post-facilitation AI from a patient was not systematically given for the second scoring after the pre-facilitation AI) and were mixed with AIs belonging to healthy subjects who participated in the study of Ernst et al. (2014a).

## 2.7. Statistical analyses

Since the aim of the facilitation process was to improve the episodic richness of past and future events, we paid attention, particularly to the internal details spontaneously provided by patients and the mean total rating scores.

Mixed ANOVA were run with the between factor of Group (experimental, verbal control and stability groups) and the repeated factors of Time (pre- and post-facilitation) and of Detail (internal and external). Analyses were conducted separately for the AM and EFT conditions. Importantly, to obtain comparative data about the effects of the MVI and verbal control programmes versus a potential learning effect on the AI, we used the results obtained on the second

AI assessment (with no in-between intervention) for the stability group. In this context, the facilitation programme and a third AI were presented (after the second AI). Likewise, a second analysis was specifically conducted for the stability group, to explore the benefit of the MVI programme, taking into account their first AI and third AI assessment (corresponding to their pre- and post-facilitation evaluation) by means of *t*-test for dependant samples.

A subsequent statistical analysis was also conducted only for the patients who followed the MVI programme to obtain comparative data about the effectiveness of this programme on AM and EFT performance (internal details), by means of repeated measures ANOVA with the between factors of Temporal direction (AM and EFT) and Time (pre- and post-facilitation).

Finally, the robustness of treatment benefits of the MVI programme was analysed, using the post-facilitation assessment as well as the six-month re-assessment AI scores (internal details and total rating) by means of *t*-test for dependant samples. For all the comparisons, Tukey HSD *post-hoc* test (for unequal N) was used when appropriate.

### 3. Results

#### 3.1. Brain atrophy

Structural MRI data revealed signs of neural atrophy in patients in the right parahippocampal gyrus (BA 35; xyz: 20, -20, -13; Z-score: 4.00), the right cuneus

Table 2  
Mean (and standard deviation) neuropsychological baseline test scores for the three groups of patients

	Experimental group	Verbal control group	Stability group	Statistical analysis
Verbal IQ	98.29 (14.80)	95.50 (11.90)	98.62 (14.26)	$F(2, 37) = 0.16, p = 0.84$
PM12	8.76 (2.08)	8.80 (1.93)	9.08 (2.02)	$F(2, 37) = 0.09, p = 0.90$
RAVLT				
-Total mean number of words	11.47 (1.39)	12.30 (1.17)	12.66 (1.44)	$F(2, 37) = 3.04, p = 0.06$
-Delayed recall	13.12 (2.06)	13.20 (2.30)	14.15 (1.41)	$F(2, 37) = 1.18, p = 0.31$
ROCF				
-Copy	35.21 (1.13)	35.50 (0.85)	35.69 (0.63)	$F(2, 37) = 1.04, p = 0.36$
-Immediate recall	25.53 (6.93)	22.05 (4.53)	23.62 (4.38)	$F(2, 37) = 1.24, p = 0.29$
-Delayed recall	25.29 (6.24)	21.80 (4.69)	24.12 (3.81)	$F(2, 37) = 1.43, p = 0.25$
Deno 100	98.24 (2.56)	95.90 (4.79)	98.50 (1.93)	$F(2, 37) = 0.52, p = 0.59$
Stroop				
-Colours (T score)	47.53 (8.06)	47.90 (10.39)	46.15 (7.70)	$F(2, 37) = 0.14, p = 0.86$
-Words (T score)	42.00 (12.29)	47.40 (8.85)	47.23 (8.13)	$F(2, 37) = 1.30, p = 0.28$
-Interference(T score)	47.76 (9.79)	48.60 (7.47)	50.15 (12.40)	$F(2, 37) = 0.20, p = 0.81$
-Interference (T score)	49.35 (7.94)	50.10 (7.05)	53.08 (7.18)	$F(2, 37) = 0.96, p = 0.39$
Months back (sec)	12.53 (5.58)	10.40 (2.80)	9.85 (2.79)	$F(2, 37) = 1.67, p = 0.20$
Tower of London				
-Score	8.53 (1.84)	8.30 (2.11)	8.58 (1.38)	$F(2, 37) = 0.07, p = 0.92$
-Time indices	19.65 (4.23)	17.60 (3.63)	18.00 (2.17)	$F(2, 37) = 1.29, p = 0.28$
Brixton (number of errors)	16.00 (5.29)	12.40 (4.25)	13.54 (5.65)	$F(2, 37) = 1.72, p = 0.19$
Cognitive Estimation Task	4.71 (3.41)	4.50 (1.96)	4.31 (4.59)	$F(2, 37) = 0.04, p = 0.95$
Verbal Fluency				
-Categorical	20.94 (4.22)	20.00 (4.92)	21.23 (5.59)	$F(2, 37) = 1.65, p = 0.20$
-Phonological	13.24 (3.17)	12.00 (0.30)	13.54 (3.15)	$F(2, 37) = 2.67, p = 0.08$
Information Processing Speed				
-Cognitive	53.71 (10.35)	52.20 (7.00)	54.69 (17.11)	$F(2, 37) = 0.11, p = 0.89$
-Motor	45.24 (8.08)	53.50 (10.95)	49.62 (10.06)	$F(2, 37) = 2.02, p = 0.14$
-Error percentage	2.34 (3.03)	3.57 (3.73)	3.09 (3.25)	$F(2, 37) = 0.46, p = 0.62$
-Corrected score	59.76 (11.95)	57.09 (7.84)	61.33 (20.97)	$F(2, 37) = 0.23, p = 0.79$
VOSP				
-Silhouettes	23.00 (3.76)	22.20 (2.66)	23.23 (3.09)	$F(2, 37) = 0.31, p = 0.73$
-Cubes Analysis	9.47 (0.80)	9.9 (0.32)	9.92 (0.28)	$F(2, 37) = 1.55, p = 0.22$
MADRS	6.59 (5.22)	6.00 (3.89)	6.33 (3.75)	$F(2, 37) = 0.05, p = 0.94$
EMIF-SEP (total)	50.14 (16.48)	40.24 (10.16)	50.42 (16.74)	$F(2, 37) = 1.60, p = 0.21$

PM12: Progressive Matrices 12; RAVLT: Rey Auditory Verbal Learning Test; ROCF: Rey-OsterriethComplex Figure; VOSP: Visual Object and Space Perception; MADRS: Montgomery and Asberg Depression Rating Scale; EMIF-SEP: Echelle de Mesure de l'Impact de la Fatigue.

(xyz: 15, -95, 2; Z-score: 3.59), the bilateral precentral gyrus (left: xyz: -47, -12, 33; Z-score: 4.93; right: xyz: 48, -8; 30; Z-score: 4.94), the right thalamus (xyz: 14, -26, 5; Z-score: 6.52) and the right cerebellum (xyz: 12, -69, -43; Z-score: 3.55). The reverse contrast, showing brain regions with an inferior GM volume in healthy controls relative to MS patients, failed to reveal any significant clusters.

### 3.2. Neuropsychological baseline

The patients' neuropsychological (baseline) scores are presented in the Table 2. Equivalent performances between patients' groups were observed for all the cognitive domains explored. In relation to the tests' normative data, our MS patients showed impaired performance only in planning (tower of London test) and cognitive estimation (eponymy task).

### 3.3. Pre- and post-facilitation AM performance

#### 3.3.1. Mean number of internal and external details

Mean AI scores for the AM and EFT conditions for the three groups of MS patients in pre-facilitation are presented in the Table 3. The mean number of internal details provided for the AM condition in pre- and post-facilitation for each MS group is illustrated in the Fig. 2.

A significant Group  $\times$  Time  $\times$  Detail interaction was found,  $F(2, 37) = 3.77, p = 0.03, \eta_p^2 = 0.16$ . *Post hoc* analyses showed equivalent performance for the mean number of internal details in the three groups before facilitation (experimental vs. verbal control group:  $p = 0.99$ ; experimental vs. stability group:  $p = 0.99$ ; verbal control vs. stability group:  $p = 1.00$ ). A similar result was obtained for the external details before

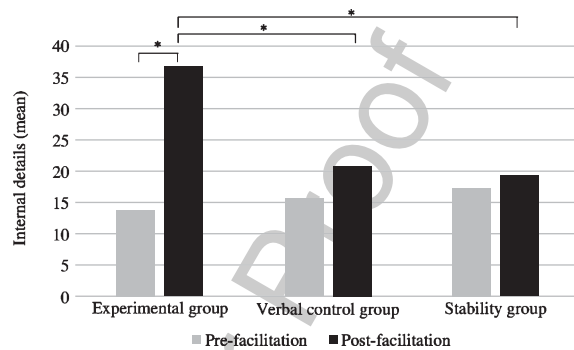


Fig. 2. Mean number of internal details for the AM condition for the three groups of MS patients in pre- and post-facilitation (\*significant difference).

facilitation (experimental vs. verbal control group:  $p = 1.00$ ; experimental vs. stability group:  $p = 0.90$ ; verbal control vs. stability group:  $p = 0.93$ ). After facilitation, a greater number of internal details was observed in the experimental group, relative to the stability group ( $p = 0.003$ ) but not to the verbal control group ( $p = 0.12$ ). No significant difference was found between the verbal control and the stability group regarding the mean number of internal details at the second AI assessment ( $p = 0.99$ ). In other words, it appeared that the verbal control group represented an intermediate group between the experimental and the stability groups for the internal detail measure. Concerning the external details, no significant difference was reported between the three groups, showing the same pattern of results than in pre-facilitation (experimental vs. verbal control group:  $p = 0.99$ ; experimental vs. stability group:  $p = 0.99$ ; verbal control vs. stability group:  $p = 1.00$ ).

The experimental group analysis showed an increase of the mean number of internal details in post-facilitation ( $p < 0.001$ ), together with an increase of the mean number of external details ( $p = 0.01$ ). However, in both pre- and post-facilitation, an equivalent number of internal and external details was observed (pre-facilitation:  $p = 0.08$ ; post-facilitation:  $p = 0.20$ ). In other words, a similar proportion of internal and external details was displayed across time, with a lower number of internal details relative to external details.

With regard to the verbal control group, irrespective of the type of detail considered, no significant changes were reported (internal details, pre- vs. post-facilitation:  $p = 0.44$ ; external details, pre- vs. post-facilitation:  $p = 0.83$ ). In addition, no significant

Table 3

Mean AI scores (and standard deviation) for the AM and EFT conditions for the three groups of MS patients in pre-facilitation

	AM condition		EFT condition	
	Internal details	Ratings	Internal details	Details
Experimental group	13.80 (4.63)	4.04 (1.33)	9.31 (5.69)	2.97 (2.02)
Verbal control group	15.73 (2.65)	4.38 (0.91)	8.58 (4.81)	3.04 (1.81)
Stability group	17.25 (3.18)	5.20 (1.37)	12.12 (5.08)	3.62 (1.85)

621 difference between the mean number of internal vs.  
622 external details was displayed for either the pre-  
623 ( $p = 0.84$ ) or the post-facilitation ( $p = 0.99$ ) sessions.

624 Within the stability group, the mean number of internal  
625 ( $p = 0.99$ ) and external details ( $p = 1.00$ ) remained  
626 stable across time. While a lower number of internal  
627 details (vs. external details) was reported in this  
628 group before facilitation ( $p = 0.01$ ), this difference dis-  
629 appeared in post-facilitation ( $p = 0.15$ ), showing an  
630 equivalent number of internal and external details.

### 631 3.3.2. Mean total rating

632 Performance for the mean total rating over time for  
633 the different groups of MS patients are displayed in the  
634 Fig. 3.

635 A significant Group  $\times$  Time interaction,  $F(2,$   
636  $37) = 26.51$ ,  $p < 0.001$ ,  $\eta_p^2 = 0.58$  was shown. Before  
637 facilitation, equivalent rating scores were observed  
638 between the three groups (experimental vs. verbal

639 control group:  $p = 0.99$ ; experimental vs. stability  
640 group:  $p = 0.38$ ; verbal control vs. stability group:  
641  $p = 0.83$ ). Between-group comparisons showed that  
642 after facilitation, the experimental group obtained sig-  
643 nificantly higher mean total rating than the verbal  
644 control ( $p = 0.001$ ) and the stability groups ( $p < 0.001$ ).  
645 However, no significant difference between the verbal  
646 control and the stability groups was evidenced at the  
647 second AI assessment ( $p = 0.99$ ). Within group com-  
648 parisons revealed a significant increase of the mean  
649 total rating within the experimental group ( $p < 0.001$ )  
650 and the verbal control group ( $p = 0.03$ ) in post-  
651 facilitation, but not in the stability group ( $p = 0.30$ ).  
652 In other words, it seemed that the verbal control  
653 group exhibited intermediate performance between the  
654 experimental and the stability groups after facilitation  
655 for the mean total rating measure.

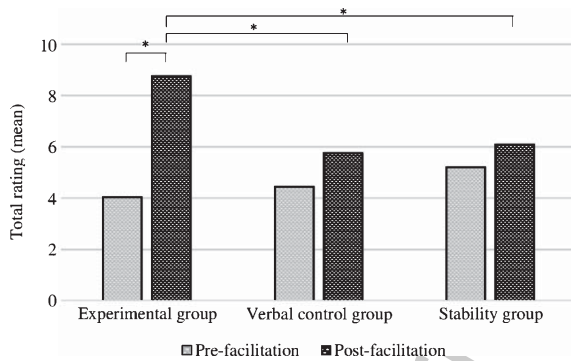
### 656 3.4. Pre- and post-facilitation EFT performance

#### 657 3.4.1. Mean number of internal and external 658 details

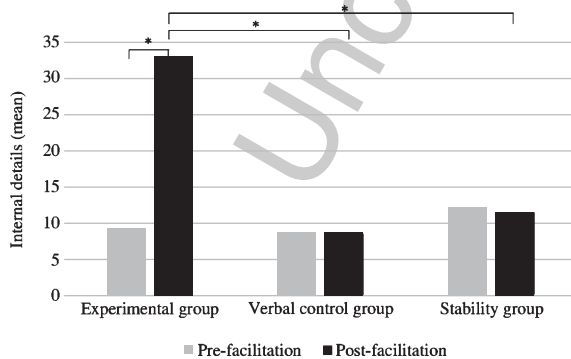
659 Turning to EFT performance, the mean number of  
660 internal details provided by each group of patients over  
661 time are shown in the Fig. 4.

662 A significant Group  $\times$  Time  $\times$  Detail interaction  
663 was observed,  $F(2, 37) = 7.27$ ,  $p = 0.002$ ,  $\eta_p^2 = 0.28$ .  
664 Before facilitation, equivalent performance was  
665 observed between the three groups for the mean  
666 number of internal details (experimental vs. verbal con-  
667 trol group:  $p = 1.00$ ; experimental vs. stability group:  
668  $p = 0.99$ ; verbal control vs. stability group:  $p = 0.99$ )  
669 and for the mean number of external details (exper-  
670 imental vs. verbal control group:  $p = 0.99$ ; experimental  
671 vs. stability group:  $p = 0.56$ ; verbal control vs. stability  
672 group:  $p = 0.99$ ). After facilitation, a greater number  
673 of internal details was observed in the experimental  
674 group, relative to the verbal control and the stability  
675 groups ( $p = 0.001$  in both cases). No significant dif-  
676 ference was found between the verbal control and the  
677 stability group regarding the mean number of internal  
678 details at the second AI assessment ( $p = 0.99$ ). Regard-  
679 ing the external details, no significant difference was  
680 reported between the three groups, showing the same  
681 pattern of results than in pre-facilitation (experimental  
682 vs. verbal control group:  $p = 1.00$ ; experimental vs. sta-  
683 bility group:  $p = 0.99$ ; verbal control vs. stability group:  
684  $p = 0.99$ ).

685 Turning to the within group comparisons, a signifi-  
686 cant increase of the mean number of internal details



635 Fig. 3. Mean total rating for the AM condition for the three groups  
636 of MS patients in pre- and post-facilitation (\*significant difference).



635 Fig. 4. Mean number of internal details for the EFT condition for the  
636 three groups of MS patients in pre- and post-facilitation (\* significant  
637 difference).

was observed in the experimental group in post-facilitation ( $p < 0.001$ ), but no changes were observed for the mean number of external details across time ( $p = 0.89$ ). While an equivalent number of internal and external details was found in the experimental group before facilitation ( $p = 0.08$ ), a greater number of internal (vs. external) details was provided after facilitation ( $p = 0.01$ ). Irrespective of the type of detail considered, no significant change was reported within the verbal control group (internal details, pre- vs. post-facilitation:  $p = 1.00$ ; external details, pre- vs. post-facilitation:  $p = 1.00$ ). Patients from the verbal control group provided a lower number of internal (vs. external) details in both pre- ( $p = 0.01$ ) and post-facilitation ( $p = 0.009$ ) sessions. Within the stability group, the mean number of internal details ( $p = 1.00$ ) and of external details ( $p = 0.99$ ) remained stable across time. Irrespective of the time of assessment, a greater number of external (vs. internal) details was found in the stability group (pre-facilitation:  $p < 0.001$ ; post-facilitation:  $p < 0.001$ ).

### 3.4.2. Mean total rating

Performance before and after facilitation for each group of patients regarding the mean total rating obtained for the EFT condition are illustrated in the Fig. 5.

Statistical analysis evidenced a main effect of Group,  $F(2, 37) = 6.78$ ,  $p = 0.003$ ,  $\eta_p^2 = 0.26$ , which showed that irrespective of the time of assessment, a higher rating score was observed for the experimental group, relative to the verbal control group ( $p = 0.009$ ). In parallel, the stability group displayed equivalent performance than the experimental group ( $p = 0.06$ ) and the verbal control group ( $p = 0.51$ ).

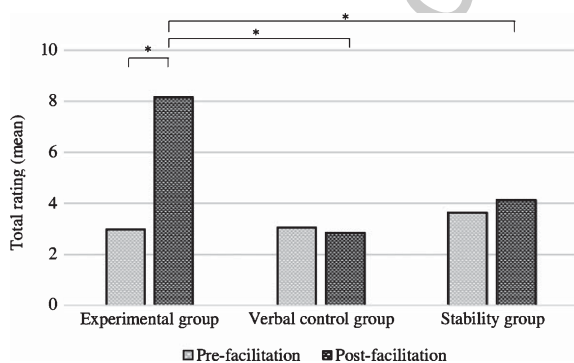


Fig. 5. Mean total rating for the EFT condition for the three groups of MS patients in pre- and post-facilitation (\*significant difference).

When the analysis took all patients as one group, a main effect of Time was found,  $F(1, 37) = 30.73$ ,  $p < 0.001$ ,  $\eta_p^2 = 0.45$ , with higher mean total rating obtained at the second EFT assessment. Nevertheless, as evidenced by the significant Group  $\times$  Time interaction,  $F(2, 37) = 29.53$ ,  $p < 0.001$ ,  $\eta_p^2 = 0.61$ , this result mainly reflects the increase of the total rating score in post-facilitation for the experimental group ( $p < 0.001$ ), since no significant changes between the two sessions of assessment was observed for the verbal control and the stability groups ( $p = 0.99$  and  $p = 0.94$ , respectively). While no significant difference was initially observed between the three groups of patients before facilitation (experimental vs. verbal control group:  $p = 1.00$ ; experimental vs. stability group:  $p = 0.97$ ; verbal control vs. stability group:  $p = 0.98$ ), after facilitation, the experimental group obtained significantly higher mean total rating than the two other groups ( $p < 0.001$  in both cases), whereas the verbal control and the stability groups showed equivalent score ( $p = 0.76$ ).

### 3.5. Post-facilitation results for the stability group

Ten patients from the stability group (from the initial group of 13) underwent the MVI programme after the second AI assessment.

Regarding the AM performance, a higher number of internal details was observed in post-facilitation, relative to pre-facilitation,  $t(9) = -6.31$ ,  $p < 0.001$ . Similar results were obtained for the mean total rating, with higher scores in post- than in pre-facilitation,  $t(9) = -10.03$ ,  $p < 0.001$ . A significant increase of the mean number of external details was also observed after facilitation,  $t(9) = -2.65$ ,  $p = 0.02$ .

Turning to the EFT performance, results showed an increase of the mean number of internal details provided in post-, relative to pre-facilitation,  $t(9) = -3.54$ ,  $p = 0.006$ . In addition, a higher mean total rating was obtained after facilitation (versus before facilitation),  $t(9) = -5.01$ ,  $p < 0.001$ . No significant change was observed for the mean number of external details,  $t(9) = -0.78$ ,  $p = 0.45$ .

### 3.6. Comparison of AM and EFT performance over time

For the patients who benefited from the MVI programme, this complementary analysis explored the potential different effect of the programme on the

episodic measures of AM and EFT performance. Regarding the mean number of internal details, no main effect of Temporal direction was showed,  $F(1, 25) = 2.90, p = 0.10, \eta_p^2 = 0.10$ . However, a main effect of Time was displayed,  $F(1, 25) = 117.47, p < 0.001, \eta_p^2 = 0.82$ , with a higher number of internal details provided in post-facilitation, whatever the temporal direction. No significant Temporal direction  $\times$  Time was obtained,  $F(1, 25) = 0.96, p = 0.33, \eta_p^2 = 0.03$ .

Turning to the mean total rating, a higher score was obtained for the past condition than for the future condition, irrespective of the time of assessment, as revealed by a main effect of Temporal direction,  $F(1, 25) = 14.35, p < 0.001, \eta_p^2 = 0.36$ . A main effect of Time was also obtained,  $F(1, 25) = 195.36, p < 0.001, \eta_p^2 = 0.88$ , showing an increase of the mean total rating in post-facilitation. The Temporal direction  $\times$  Time interaction did not reach the statistical threshold,  $F(1, 25) = 2.79, p = 0.14, \eta_p^2 = 0.08$ .

### 3.7. Long-term follow up assessment

Descriptive results of the mean AI scores obtained immediately after the facilitation and at the long-term follow up assessments for the AM and EFT conditions are presented in Table 4. The present statistical analyses were conducted on the 15 patients re-assessed to date (on a total of 27 patients who benefited from the MVI programme).

Regarding the AM condition, the analysis of treatment benefit robustness after the MVI programme showed no significant difference between the post-facilitation session and the six months assessment for the mean number of internal details,  $t(15) = -0.24, p = 0.81$ , and the mean total rating,  $t(15) = -1.08, p = 0.29$ .

Turning to the EFT condition, a slight decrease of the mean number of internal details provided by

the patients between the post- and the long-term assessment was observed,  $t(15) = 2.39, p = 0.03$ . Nevertheless, a complementary analysis revealed that the mean number of internal details provided at the long term assessment remained significantly higher than in pre-facilitation,  $t(15) = -4.16, p = 0.001$ . Regarding the mean total rating, performance were stable over time,  $t(15) = 0.53, p = 0.60$ .

Moreover, in every case, whatever the temporal direction, the mean number of internal details and the mean total rating remained above the mean scores obtained by the group of healthy controls, which initially determined the presence of an AM/EFT impairment (Ernst et al., 2012).

### 3.8. Individual benefits following the MVI programme

Importantly, beyond the results obtained at the group level, a particular emphasis was also made on the individual benefit of the MVI programme. As the presence of an AM/EFT impairment was initially established based on our normative database, for each MS patient, the mean number of internal details and the mean total rating obtained after facilitation were compared to the normative scores. Twenty-five out of the 27 MS patients (experimental and stability groups), who underwent the MVI programme showed a normalisation of their AM and EFT performance. For the AM condition, one patient from each group showed scores below the threshold, and for the EFT condition, two patients from the stability remained under the normative threshold.

### 3.9. Semi-structured interview

#### 3.9.1. Pre-facilitation comments

Before the facilitation programme, the great majority of patients expressed difficulties for AM and EFT, which appeared as undifferentiated between the groups of patients.

Regarding their comments about the AI assessment, for the AM condition, patients evoked mainly difficulties to retrieve/select a specific event, with further difficulties to provide details about memories. This was accompanied by low emotional reviviscence and a feeling of "emotional distance" with their memories. Moreover, when assessing the vividness and the mental visual quality of their memories, patients expressed that their memories were like some "flashes"

Table 4

Mean AI scores (and standard deviation) for the AM and EFT condition obtained at T1 (no delay) and T2 (6 month) post-facilitation

	No delay post-facilitation	Six month-follow up
AM condition		
Internal details	38.16 (7.77)	38.85 (11.94)
Rating	9.15 (1.37)	9.67 (2.04)
EFT condition		
Internal details	35.96 (22.65)	28.95 (16.88)
Rating	8.04 (2.36)	7.71 (3.21)

849 or “motionless pictures”. For their self-assessment in  
850 the context of everyday life, their comments largely  
851 overlapped with those gathered for the AI performance.  
852 The great majority of patients also mentioned concrete  
853 life situations, in which they felt uncomfortable due to  
854 the fact of forgetting or having difficulties to remember  
855 some details or more simply, having doubts about their  
856 memories.

857 Concerning EFT, we obtained similar feedback than  
858 for the past events with a particular difficulty to find  
859 future events that were not memories. This led the great  
860 majority of patients to find the EFT condition harder  
861 than the AM condition. Moreover, patients found dif-  
862 ficult to focus on a future event and to elaborate on it  
863 since a lot of possibilities could be considered. With  
864 regard to everyday life, albeit present, less concrete  
865 examples of daily life difficulties explicitly related to  
866 EFT impairment were provided in comparison with  
867 memory problems.

### 868 3.9.2. Post-facilitation comments

869 3.9.2.1. *MVI facilitation programme.* For the patients  
870 who underwent the MVI programme (experimen-  
871 tal and stability groups), post-facilitation comments  
872 unanimously acknowledged a greater easiness of  
873 retrieval/imagination, with more detailed memories/  
874 projections. A major change was also recounted con-  
875 cerning the vividness of past and future events, which  
876 became dynamic “mental films”, with reports about  
877 motions present in their mental simulations. Further-  
878 more, a greater emotional intensity and feeling of  
879 re/pre-living events were mentioned by the patients  
880 (also qualitatively noticed by the neuropsychologist  
881 during some events’ evocation). No differential effect  
882 of the programme on AM and EFT was noticed by the  
883 patients.

884 Regarding the benefits in daily life, the same obser-  
885 vations than those expressed during the AI testing  
886 were reported, and a few patients commented that they  
887 needed more time to be sure about of the benefits of  
888 the programme in everyday life. In general, an effective  
889 treatment receipt seemed to have been obtained since  
890 the patients acknowledged an easy use and transfer of  
891 this technique in their daily life functioning. Addition-  
892 ally, spontaneous feedback of some patients’ relatives  
893 also supported the effective transfer and benefits of the  
894 MVI programme in daily life.

895 The long-term follow-up assessment led to the same  
896 observations and most of the patients reported that the

897 further use of this technique was easy and now sponta-  
898 neously carried out. Moreover, at six months, several  
899 patients also reported that they had a more general  
900 feeling of self-confidence in social and professional  
901 situations, with a feeling of internal locus of control  
902 and vitality. We provided here illustrations of some  
903 patients’ comments:

904 Patient FZ: “It made it possible for me to learn how to  
905 visualise things, and by so doing, I am able to control  
906 them in a different way, past or future, I can control  
907 them. It sounds very positive to me. [ . . . ] We realise  
908 that we knew lots of things, but that we were not aware  
909 that we knew them, hidden memories [ . . . ]. It helps a  
910 lot.

911 Patient CC: “Actually, I had never imagined that I  
912 could tell so many things . . . It’s as if all these things  
913 had been in a box, and the box put aside somewhere.  
914 Since I don’t need it, I let it where it is. And if I need  
915 to remember something, I will search the box, I will  
916 open it and start to look inside”.

917 Patient PP: “Yes, there are more details than the last  
918 time. Actually, it’s as if I am wearing reading glasses  
919 now in comparison with the last time. It used to be  
920 more or less blurred, but now, it seems more fluent to  
921 me, it comes very quickly”.

922 Patient IB: “Before I was panicking, because I knew  
923 that I would be unable to remember. I’m not panick-  
924 ing anymore. As we get along the sessions, I have the  
925 feeling that I live the thing. I’m in, I live it, and I’m in  
926 my thing. I feel less stressed, more self-confident and  
927 so, for the birthday, I haven’t thought about it before,  
928 but now, it is the moment and I will think about it, but  
929 serenely”.

930 Patient MM: “I see something, and something else  
931 in relation to the first thing comes with it. A memory  
932 comes to my mind and I’ve noticed that I can detail it.  
933 I have more memories. If I remember something, I can  
934 focus on that, on the memory, and look for details. I’m  
935 able to do that. Even for emotional details. I’m positive  
936 that from now on, it will help me more and more. [ . . . ]  
937 It’s easier to make a decision, whatever it is. I used to  
938 hesitate a lot, more than presently. Now, if I don’t want  
939 something, I know that I don’t want it, and I know what  
940 I want . . . for me, it’s obvious. I wouldn’t have dared  
941 before. So, all in all, it has restored my self-confidence,  
942 that’s what I feel . . . It’s true, I can feel OK with myself  
943 again”.

944 Patient NK: “I think that I found it quicker and it  
945 was clearer than the first time we went through these  
946 exercises. Even when I remembered a scene, before,

I saw it from far away, while now, the feeling is that I've relived some events at the present time. It's true that sometimes, you realise that the sessions are gaining their own place. It's not every time but sometimes, you've gone a bit of the path, it's done without really realising it. I would never have thought that I could use little tricks like this. It's something that could help me anyway in my life".

Patient DR: "Sometimes, people were surprised because I was able to remember dates, and things like that, but when I became ill, all that was finished, I started having difficulties to keep being myself, I've started... There were things that I had really forgotten. [...] When you came to see me, I thought it providential. Because it was really scaring... So for me, it's all benefit. I realise that it helped me to be more efficient. I do it more naturally, I ask myself less questions. It's natural, like a mechanism I have by now, a process that I've integrated. And I've noticed that if I don't remember one detail, I go for another, and remembering then three others details, suddenly, something triggers and I can come back to the first point".

Patient VW: "I have the feeling that I'm more the actress of my own life now, whereas before, I was present at some point, but I failed to feel that it was me who was writing the story. I was present, people were talking about something but I had difficulties to take part in, I had difficulties to participate in conversations. Now, I have the feeling that, when a conversation starts, I have something to say, I'm more engaged in the conversation".

**3.9.2.2. Verbal control programme.** Although no reliable statistical evidence of improvement was noticed in the verbal control group, a general impression that the second AI testing was easier than the first one was reported by the patients. This was explicitly related by the patients to the fact that the exercise was not new for them. However, no obvious changes were mentioned regarding the difficulty to retrieve/imagine specific past and future events, the amount of details, emotional intensity or vividness of the personal episodes during the AI assessment. Concerning their comments on everyday life situations, no clear benefit in relation to memories or future projections was reported. Nonetheless, several patients acknowledged that they felt more ready to pay attention since they had the impression that the programme had helped them to better concentrate when required.

#### 4. Discussion

The aim of the present study was to explore the possibility to jointly improve AM and EFT functioning in RR-MS patients through the use of a MVI-based facilitation programme and in the context of a randomised controlled clinical trial. While previous investigations already demonstrated AM improvement following neuropsychological interventions in various clinical conditions (Berry et al., 2007; Pauly-Takacs et al., 2011; Neshat-Doost et al., 2013; Moradi et al., 2014) and notably in RR-MS patients (Ernst et al., 2012, 2013), this study is the first, to our knowledge, to have extended this finding to EFT abilities.

As expected, our results demonstrate a benefit of the MVI programme on the simulation of personal past and future events, expressed by an enhancement of the amount of episodic details and of their qualitative episodic richness. Overall, no differential improvement was observed for AM and EFT conditions, which seemed to benefit both from the MVI programme. The increased amount of episodic details was accompanied by an increased number of external details for the AM condition, but not for the EFT condition. How to explain the increase of external details in AM? At a clinical level, it is likely that this was due, at least partially, to a side effect, so to speak, of the facilitation programme, which must have encouraged the patients to provide more information about AMs. In the same vein, James et al. (1998) suggested that older adults also tended to provide additional semantic information about their memories to clarify points when facing to a young examiner with different life experiences. Moreover, we observed that after facilitation, our patients shared their impressions, which arose while recollecting. Importantly, they would make spontaneous comments such as 'The last time I have talked about that with X, I didn't remember all these things; I would have never thought I would'. Other comments dealt with the personal significance of the events. After facilitation, patients were also more prone to evoke other memories related to the central event that came to their mind in the flow of recollection (e.g. a patient evoked a car accident as the central event and remembered additional episodic details, belonging to different episodes that were directly related to the accident, such as her appointment with her insurer, or with the mechanic). The latter clarification is doubly important since it shows the effects of the programme and also illustrates a different level of explanation

concerning the increased number of external details. Indeed, as stated above, we follow Levine et al.'s (2002) AI method, including their scoring instructions. As it happens, all the episodic recollections not belonging in the central event are recorded as being "external details", because not directly related to the central episodic even though there are episodic in nature. To account for the difference in the increase of external details in AM and EFT in post-facilitation, we would like to remind that the EFT condition is cognitively considerably more demanding than AM, especially due to executive processes. Moreover, the EFT impairment is more severe than the deficit shown on AM, in our patients (Ernst et al., 2014a). The absence of an increase of external details in the EFT condition is most likely related to the difficulty to make similar comparisons of previous attempts to evoke this particular event in daily life or to mention thematically or causally related future events.

Our findings are also supported by the normalisation of AM and EFT scores, namely the mean number of internal details, in the great majority of our MS patients, relative to our normative database (which initially established the presence of an impairment). An additional main finding is that this performance increase in the context of AM/EFT assessment was also accompanied with a perceived benefit of this technique by patients in their everyday life. Indeed, patients mentioned an easy use and transfer of the MVI strategy in their daily functioning. This last point probably contributed to the general good maintenance of the benefit also observed at the long-term follow up. Nevertheless, regarding the long-term reassessment of EFT performance, the mean number of internal details showed a slight decrease, even if this score remained superior to the normative threshold and to the pre-facilitation performance. Clinically, considering that the last step of the MVI programme focused on the construction of self-involved fictitious scenes, it is possible that immediately after facilitation, following the dynamic established through the programme, an inflated performance could be observed for the EFT condition. This same effect could not be observed for the AM condition, since for the past, contrary to the future events, restrictions regarding the details associated to the event are present to keep a good correspondence with the initial event. However, since no significant change of the qualitative episodic richness of future events was noticed over time, it seems that the general improvement of EFT performance remained present at six months.

Importantly, this enhancement did not seem due to a learning effect on the AM/EFT test, since no significant change was observed when the test was carried out twice, in an equivalent timeframe and with no intervention in-between (the stability group). Furthermore, the AM/EFT improvement was not likely related to a 'nursing effect', since MS patients who followed the sham verbal facilitation programme showed no evidence of enhanced performance in post-facilitation. Moreover, AI scores from the verbal control group remained below those obtained by MS patients after the MVI programme but were equivalent to those obtained by the stability group, at the second AI assessment.

Our results complete those previously obtained by Ernst and colleagues (2012, 2013), by controlling the methodological issues. The present results, and particularly the successful transfer of the benefits to everyday life, were probably helped by the fact that AM and EFT are ubiquitous in our daily life and rely on personal real-life events. The selectivity of the deficit may also have helped the good completion of the facilitation sessions, and the further use and integration of the strategy in daily life (Evans et al., 2003).

Overall, based on our findings, we suggest that early neuropsychological interventions in MS patients seem to lead to positive outcomes for AM and EFT functioning, cognitive functions which seemed both particularly sensitive to MS pathology (Ernst et al., 2014a). As previously mentioned, the programme's origins were clinically grounded observations regarding AM impairment in RR-MS patients and, the extension of this deficit to EFT together with the deleterious impact of these difficulties in daily life, reinforced the importance of the development of this kind of interventions in MS patients. It is possible that the use of early interventions of this kind could be decisive to compensate or delay the expression of cognitive impairment, which have an important negative impact on quality of life in MS patients (Chiaravalloti & DeLuca, 2008).

From a theoretical perspective, the results show that a single cognitive strategy can contribute to AM and EFT improvement, which support the strong relationships between the two temporal directions (see Schacter et al., 2012 for a review). Our findings also contribute to demonstrate that scene construction is a key cognitive process in mental time travel (Hassabis & Maguire, 2007). The latter point is related to the authors' hypothesis that the ability of mentally generating and maintaining a complex and coherent

scene constitutes the main core process of AM and EFT. Scene construction would require the reactivation and retrieval of a range of fragments of information (semantic, contextual, and sensory elements), which are subsequently integrated into a coherent spatial context for their further mental manipulation and visualisation (Hassabis et al., 2007). From a neuroanatomical standpoint, scene construction is supported by a distributed brain network, involving the hippocampus, the parahippocampal gyrus, the retrosplenial cortex, the posterior parietal region and the ventromedial prefrontal cortex (Hassabis et al., 2007). On these bases, whether scene construction is the key cognitive process at the origin of the AM/EFT improvement in our MS patients, the next question would concern the functional underpinnings of this enhancement. Indeed, it could be hypothesised that increased brain activations would be observed within the scene construction core brain network, which in turn would lead to the question regarding the similarities and differences that could be observed between AM and EFT neural networks following their improvement. In fact, while AM and EFT share a common core brain network, several investigations have highlighted discrepancies in the recruitment of some specific brain areas and in their sensitivity to phenomenological properties of past and future events in healthy subjects (see Schacter et al., 2012 for a review). In particular, increased brain activations have been reported in the frontal and medial temporal lobe regions during the imagination of future events. To our knowledge, no study to date has explored the potential similarities and differences between AM and EFT brain networks in the context of brain activation changes induced by an effective neuropsychological intervention in patients. In the case of MS patients, studies on the functional underpinnings of AM impairment remain very scarce, and no study to date has explored the functional changes associated with EFT impairment in these patients. Only one of our previous studies, to our knowledge, explored the functional brain activation changes associated with AM impairment and showed that functional changes were mainly observed in the bilateral prefrontal regions (Ernst et al., 2014b). Investigations along these lines could contribute to the identification and understanding of the brain regions sustaining both impaired and improved AM/EFT performance in MS patients.

In summary, the major finding of this study is that AM and EFT impairment could be efficiently improved by means of a facilitation programme and that the use

of a MVI strategy seemed easily integrated and resulted in significant benefits in their daily life functioning. More generally, we hope that this study and its positive outcomes could encourage future investigations in different clinical settings. As mentioned above, the facilitation programme requires to be probed in other MS subtypes or different clinical conditions presenting a similar profile of AM and EFT impairment. The clinical interest would be important bearing in mind the central roles of AM and EFT in everyday life, and more generally in well-being (Szpunar, 2010; Schacter et al., 2012).

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### Declaration of interest

The authors report no declaration of interest.

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