SPECIAL SECTION

FORGETTING DUE TO RETROACTIVE INTERFERENCE: A FUSION OF MÜLLER AND PILZECKER'S (1900) EARLY INSIGHTS INTO EVERYDAY FORGETTING AND RECENT RESEARCH ON ANTEROGRADE AMNESIA

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ABSTRACT

Ebbinghaus' seminal work suggested that forgetting occurred as a function of time. However, it raised a number of fundamental theoretical issues that still have not been resolved in the literature. Müller and Pilzecker (1900) addressed some of these issues in a remarkable manner but their observations have been mostly ignored in recent years. Müller and Pilzecker (1900) showed that the materials and the task that intervene between presentation and recall may interfere with the to-be-remembered items, and they named this phenomenon "retroactive interference" (RI). They further asked whether there is a type of RI that is based only on distraction, and not on the similarity between the memoranda and the interfering stimuli. Their findings, and our follow up research in healthy volunteers and amnesiacs, confirm that forgetting can be induced by any subsequent mentally effortful interpolated task, irrespective of its content; the interpolated "interfering" material does not have to be similar to the to-be-remembered stimuli.

Key words: retroactive interference, memory, forgetting, anterograde amnesia, history of neuroscience.

HOW DO WE FORGET?

The forgetting research debate was set by Herman Ebbinghaus' in 1895 and is still very much active today, the most prominently discussed culprits being Decay and Interference.

Decay?

Decay theory evolved as a product of Ebbinghaus' (1895) seminal research in which he elucidated that forgetting appeared to occur as a function of time with learned material decaying as time went by (see Figure 1).

However the time between encoding and recall in memory experiments is rarely spent in a "vacuum", a condition required for the "time" theory to be conclusively accepted. Typically the participant is engaged in further tasks, which range from experimental to everyday life activities.

Interference?

This opens the door to the question of whether the materials and tasks that occupy this time might be involved in the forgetting process by interfering with the to-be-retained material (i.e., retroactive interference) (see Figure 2).

A simple yet powerful method to investigate whether or not subsequent tasks or material directly affect forgetting is to include a filled and an unfilled delay interval between item presentation

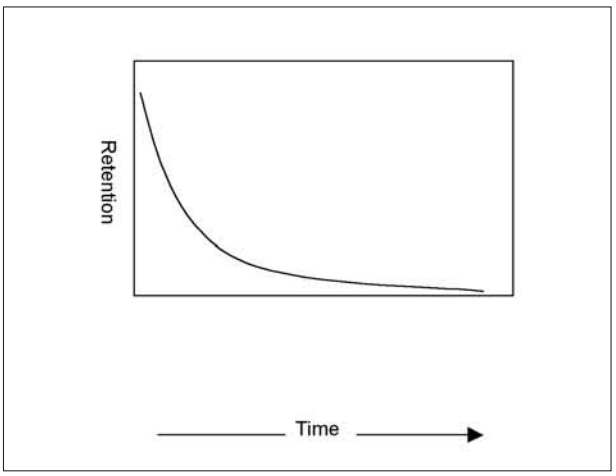

Fig. 1 – *Forgetting as a function of time.*

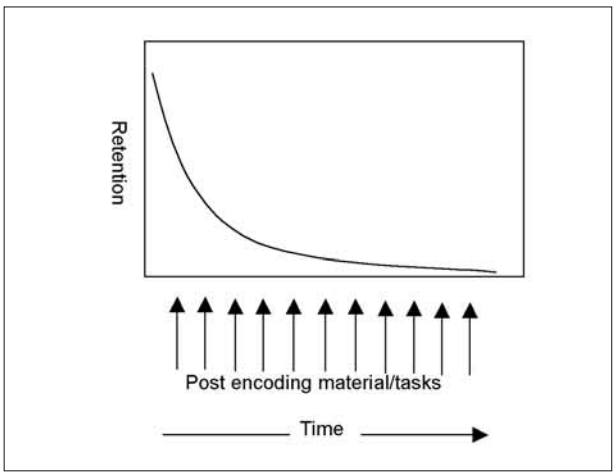

Fig. 2 – *Forgetting due to the material that occupies time.*

and recall. If indeed forgetting occurs solely as a function of time, no difference should be observed following the unfilled and filled conditions. If however subsequent material/tasks do play a role in forgetting, recall should be higher following the unfilled condition. Such methodology was in fact widely used at the end of the 19th and beginning of the 20th century as a number of memory researchers (e.g., Bigham, 1894; Müller and Pilzecker, 1900; Skaggs, 1925; McGeoch and McDonald, 1931) started to appreciate that time intervals between learning and remembering were invariably filled and that such material could have a detrimental effect on memory. Ebbinghaus (1895) himself stated that "If syllable series of a definite kind are learned by heart and then left to themselves, how will the process of forgetting go on when left merely to the influence of time *or the daily events of life which fill it*?" (Ebbinghaus, 1895, p. 65). Bigham (1894) highlighted not long after Ebbinghaus' (1894) findings that "unfilled intervals represent a rare and artificial condition for our memory; nearly all our recollecting is done when *optical or acoustical impressions fill the interval between learning and reproducing*. The following experiments endeavor to submit this question to an experimental test" (p. 458). This "experimental test" revealed that "the filling of the intervals hinders memory" (p. 459).

Indeed numerous other experiments such as the main and pioneer studies into RI by Müller and Pilzecker (1900) provided strong evidence against a (sole) time based theory and for an interference theory. The notion that forgetting could be induced by subsequent interference was also later supported by Jenkins and Dallenbach (1924) who found that people recalled more nonsense syllables when they slept between presentation and recall than when they stayed awake. Such reasoning was also voiced by Skaggs (1925) who stated that: "Attentive work, following the original learning of the reconstruction test, works in some positive way a clearly detrimental influence on the retention and recall of this original learning" (p. 14). This consequentially led to the notion that RI played a somewhat large role in the human forgetting process.

However this type of interference theory was not to last very long. In 1957 Underwood published a paper in which he strongly rejected RI as a cause of forgetting. He introduced his paper by writing "I will try to show that very little of the forgetting can be attributed to an interfering task learned outside the laboratory during the retention interval" (p. 49). Instead he strongly argued that forgetting is mainly caused by a second form of interference, proactive interference (PI), the interference of to-be-retained material by previous as opposed to subsequent information. In short, Underwood (1957) reports a correlation between percent list recall and the number of lists presented prior to the to-be-retained list. He therefore argued against the time based theories of forgetting as well as strongly rejecting the then prominent RI account of forgetting. He stated: "An analysis of the current evidence suggests that the classical Ebbinghaus curve of forgetting is primarily a function of interference from materials learned previously in the laboratory. When this source of interference is removed, forgetting decreases from about 75 per cent over 24 hours to about 25 percent" (p. 58). However this theory appeared to be flawed from the very start as (a) it could not explain the benefit of sleep found by Jenkins and Dallenbach (1924) and (b) PI did not appear to play a major role in everyday forgetting (see Wixted, 2004 for a full review of PI theory and its history).

Wixted (2004) argues that such premature and flawed theory of PI may have consequentially led to a lack of confidence in the then prominent interference theory. While the general concept of PI and RI has survived to the present day, such is certainly not the case for the *original* RI theory and definition proposed by Müller and Pilzecker (1900). Indeed it is astounding that their research, which gave rise to interference theory rarely is featured in modern Psychology articles, with a few notable exceptions (e.g., Wixted, 2004, 2005; Lechner et al., 1999). Within the Psychology literature, this is also evident for consolidation (with few exceptions, e.g., Bosshardt et al., 2005), a notion closely related to RI and a second major concept introduced by Müller and Pilzecker (1900) in their 300 page monograph. However, the idea of consolidation has been adopted and advanced in the neurosciences and biological sciences (e.g., recent articles by McGaugh, 1999, 2000; Dudai, 2003; Stickgold, 2005; and Stickgold and Walker, 2005; for a discussion see also Wixted, 2004, 2005).

This paper will address the following questions:

a) What does the early work of Müller and Pilzecker (1900) indicate about normal forgetting?

b) What does RI really depict?

c) Could anterograde amnesia be a disorder characterized by a high susceptibility to RI?

d) How can the beneficial effects of minimal RI be explained in terms of cognitive and neural processes?

Setting the Scene

Müller and Pilzecker

The seminal work on RI by Georg Elias Müller (1850-1934) (Figure 3) and his student Alfons Pilzecker took place during 1892 and 1900 at the Psychology Institute of the University of Göttingen (Germany).

The Institute, which in fact was founded by Müller himself in1887, still bears his name today (Georg-Elias-Müller Institut für Psychologie). It was the second Psychology Institute to be

Fig. 3 – *Photo of Georg Elias Müller.*

established worldwide and it is said that this institute quickly turned into a Mecca of experimental psychology renowned for its significant research in the areas of psychophysics, sensory psychology and memory function. One of the research projects conducted within the Institute's memory function area was an extensive study on associative memory by Müller and Pilzecker (1900). It was this research that led to their "discovery" of RI.

The aim of Müller and Pilzecker's (1900) research was to present participants with nonsense syllable pairs to investigate (a) the amount of learning repetition required for the participants to be able to recall the second (unemphasised) syllable when cued with the first (emphasised) syllable and (b) the percentage of correctly recalled syllables as well as time required for recall when repetitions were kept constant.

Müller and Pilzecker's (1900) Methods

Materials

In order to investigate this in a controlled fashion Müller developed an ingenious apparatus for presentation and recall of to be remembered stimuli (see Figure 4):

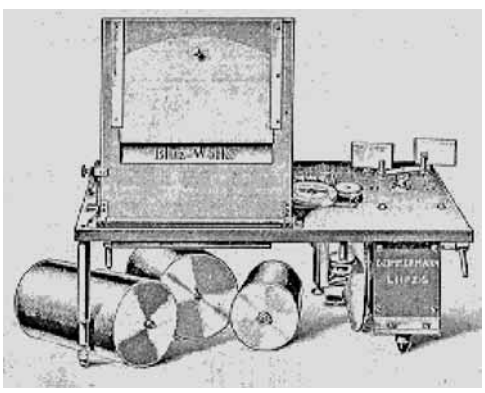

Fig. 4 – *The memory drum utilised by Müller.*

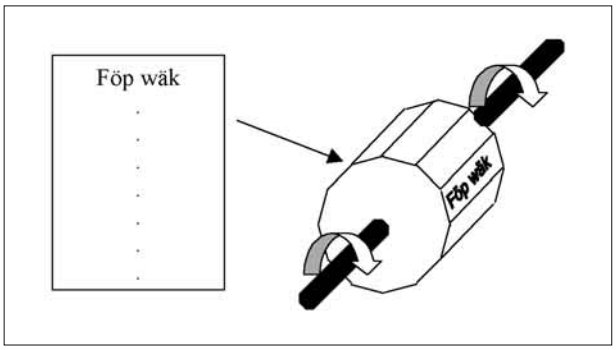

Fig. 5 – *The prism drum.*

A prism drum (Figure 5) consisting of 12 sides, which could be turned around via a horizontal axis served as the main display unit of the stimuli. Numerous nonsense syllable pair lists were printed on paper, each pair being displayed in a vertical fashion leaving sufficient space between pairs for each pair to take over one of the 12 sides of the prism (the maximum syllable pairs was 12).

The prism drum was situated behind a wall, which contained a small slot that matched the size of one prism drum side (see Figure 6).

Procedure

The participant sat in front of this wall so that he/she could only ever see one prism side and therefore only one syllable pair. During the learning phase the prism drum was rotated at a constant speed so that presentation time for all syllable pairs was constant across lists. Participants were asked to emphasize the odd (the first) syllable of every pair during the reading of the presented material. Drum rotation time as well as repetitions of main lists differed across experiments. During recall a shield, which was held in position via an electromagnet, covered the peek hole prior to presentation of the first syllable (see Figure 7). The experimenter then opened an electrical circuit, which resulted in the shield falling down and thereby enabling the participant to see the first stimuli (the emphasized syllable). The falling of the shield furthermore led to the opening of a contact resulting in a disruption of a current, which flowed through a Hipp's chronoscope. This in turn activated a clock, which

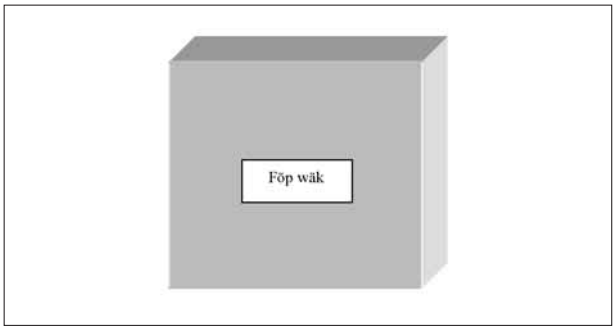

Fig. 6 – *The prism drum behind the wall.*

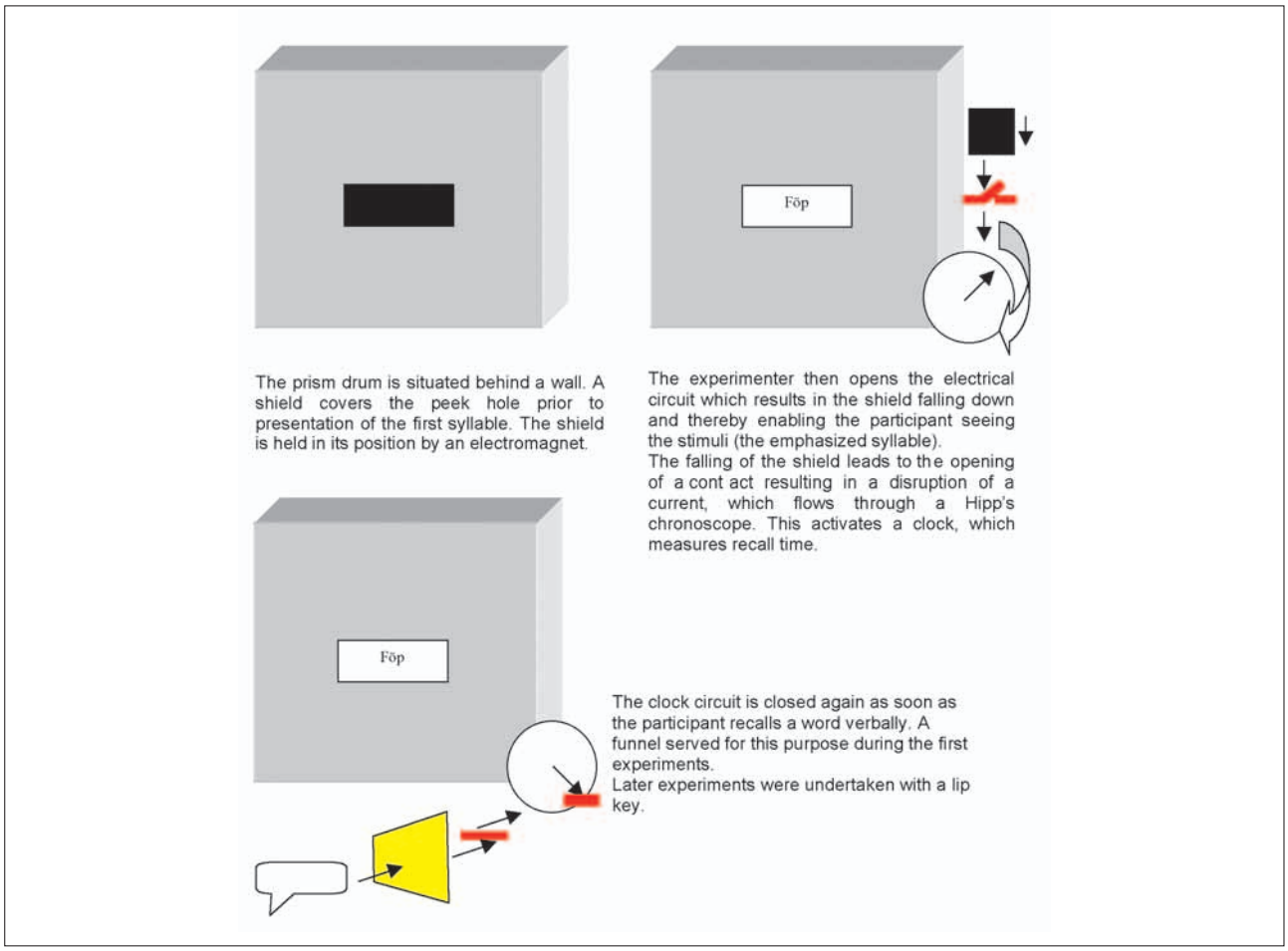

Fig. 7. *Recall procedure.*

measured recall time. The clock circuit was closed again as soon as the participant made a verbalization, which was picked up by a funnel during the first experiments. Later experiments were undertaken with a lip key (on which the participant purses his/her lips, then breaking a circuit by speaking). Having provided a response the participant lifted the shield up to its starting position (the circuit required for the electromagnet to hold the shield in position was closed by the experimenter just prior to the participant lifting the shield). The participant then turned the prism drum so that the next syllable would be positioned behind the shield. A special lock enabled the participant to only turn the drum by a certain degree (i.e., by one side). Participants were actively engaged in helping out in this way so that any thoughts about the syllables could be minimized.

Müller and Pilzecker's (1900) Experiments on Associative Memory Summary of Topics in Their Book

Müller and Pilzecker's (1900) book contains various chapters, all of which focus on varying aspects of associative memory. (Chapter 1 – Experimental procedure, Chapter 2 – The relationship between reproduction time and association strength and other factors, Chapter 3 – The perseveration tendencies of stimuli, Chapter 4 – The interaction and competition of simultaneous reproduction tendencies, Chapter 5 – Retroactive inhibition, Chapter 6 – The initial reproduction tendency, Chapter 7 – About the various types of reproduction tendencies, which are triggered by trochaic reading of syllable lists. Analysis of false memory, Chapter 8 – Various). The chapters that are most interesting and relevant to the present discussion are chapters 3 (The perseveration tendencies of stimuli) and 5 (Retroactive inhibition).

Reproductive Tendencies and the Birth of Consolidation Theory

Chapter 3 concerns the reproductive tendencies of recently learned verbal material and introduces the concept of memory consolidation to psychological research. The authors state: "Every stimulus owns a perseveration tendency following its appearance in consciousness. This is a rapidly declining tendency to reappear in consciousness"[1] (Müller and Pilzecker, 1900, p. 58). The authors

[1]Original German text*: "Jede Vorstellung besitzt nach ihrem Auftreten im Bewußtsein eine Perseverationstendenz, d.h. eine im Allgemeinen schnell abklingende Tendenz, frei ins Bewußtsein zu steigen".*

provide the following everyday life example: If a scientist spends hours attending to an interesting phenomenon, such a phenomenon may suddenly reappear as a visual image if the scientist is not doing any effortful task afterwards. Müller and Pilzecker (1900) explain that the origin of their term "perseveration" tendency comes from the field of Neurology and Psychiatry where this term is used to describe "disruptions in the formal procedure of a cerebral action, which manifests itself as a tendency to repeat an already undertaken function (either centrifugal or centripetal direction) straight after or shortly after and also at unsuitable locations/moments" (p. 60).

The authors cite Von Söldner (1894) who argued that perserveration could also appear in healthy people but to a lesser degree. Müller and Pilzecker (1900) therefore decided to adopt this term for their finding. They provide further everyday examples such as the all too familiar phenomenon of the earworm or the tendency for prior images and thoughts to enter consciousness against one's will and in a random manner if (a) one has the ability to concentrate mentally on such images and thoughts in the first instance and (b) "consciousness" is not being used for any other subsequent effortful task. In light of the current discussion on RI, point b in particular is of special interest as the authors tentatively mention the requirement of an "empty mind" for stimuli to reappear in consciousness.

The authors predict from the above reported everyday experiences that the perseveration tendencies of a given stimulus list can be weakened by strongly diverting one's attention to another stimulus. And indeed various experiments such as their Experiment 6 elucidated a dampening of the reappearance of the to-be-learned syllables during a delay interval by the reading of a subsequent syllable list.

However, the authors raise the critical issue that this *effortful task* may not actually lead to poorer results due to a decline in the frequency of reappearances of the presented stimuli in consciousness per se but that this task may actually hinder *consolidation* of the previous association. Hence Müller and Pilzecker (1900) state that the perseveration tendency may in fact be useful for consolidating the associations between the syllables. This is followed by their revelation that such early speculations were indeed true. They state: "We will see in Chapter 5 that the above hinted hypothesis is applicable and that indeed the associations between syllables of a list do not only depend on the number of readings and the behaviour of the participant during reading, but also on the degree to which the participant is engaged mentally following the end of reading" (p. 68).

Despite revealing such confirmation of earlier speculations in this chapter it is important to note that the authors do not appear to have planned research into RI but were seemingly motivated to do so after obtaining some interesting data in one of their earlier experiments (Experiment 29) on reproduction tendencies.

TABLE I
Recall percentage

List	Percentage correct
1	58
2	58
3	61
4	39

Retroactive Interference (RI)

The Discovery of RI

The aim of this experiment (Experiment 29), which lasted 25 days, was to investigate whether there was a difference between the reproduction times (time taken between recognition of the presented stimuli and reproduction of the associated stimuli) between associations that were learned 24 hours or 11 minutes before recall.

The participant was firstly presented with List 1, which was followed by a 36 second unfilled interval that was followed by List 2. There were five further repetitions of this sequence, which was followed by a 10 minute delay interval. The participant was then presented with the odd syllables and asked to recall the associated even syllables. Having recalled lists 1 and 2 the participant was given a relaxation interval. This was followed by presentation of lists 3 and 4, which were separated by 6 minutes. Recall of these two lists took place 24 hours after the learning phase. No difference was found between recall of lists 1 and 2 and that for lists 3 and 4 with respect to reproduction time. However some interesting findings emerged with respect to recall percentage (see Table I).

Interestingly the percentage correct was identical for List 1 and 2. The authors pointed out that this was indeed intriguing because Mrs. Müller, the participant, stated that the very short time period between reading of List 1 and List 2 (36 seconds) led to the *wiping out* of List 1 by List 2. The authors speculate whether reading of List 2 did indeed impede List 1 but that the participant was fatigued by the time List 2 was read, leading to the participant performing poorly on List 2, which consequently resulted in a balance of scores. In other words there could have been a *hidden* detrimental effect of List 2 reading on List 1. The authors stated that the reading of list 4 could not have resulted in such a detrimental effect on list 3 as List 2 did on List 1 due to the relatively long interval between list 3 and 4 (6 minutes). In a replication study (Experiment 30) a further participant stated that immediate reading of a

second list was detrimental for the first list. However this participant showed increased recall for List 2, which was therefore in line with the participant's subjective feedback. These two studies gave rise to Müller and Pilzecker's (1900) prediction that "the processes, which serve the production of a read syllable list also continue for a certain time after the reading of such syllables, but that they can be weakened via a different mentally effortful task during this time resulting in an inhibition (more specifically a developmental inhibition) of the read syllable lists via this mental effort" (p. 179). They subsequently stated: "In the absence of any other short name we want to term this type of inhibition retroactive inhibition because it relates to a process which has already terminated externally; to the already accomplished reading of a syllable list" (p. 179).

The better performance in List 2 recall than List 1 recall in Experiment 30 provides evidence that the data in Experiment 29 did possibly result from a compensation of the RI effect by fatigue. However, the authors acknowledged that the advantage of lists 2 and 4 in Experiment 30 may have been triggered by the participant attending to the first lists with lesser degree than to the later lists. Hence they claim that critics could in fact argue that the improved performance in lists 2 and 4 were not due to their newly coined RI but simply to a rise in attention to the second lists at presentation. In order to verify the existence of RI the authors ran seven experiments (Experiments 31-37), which were designed to exclude the possibility of the above stated alternative hypothesis. A selection of these experiments will be described and discussed subsequently.

In Search of Evidence for the Existence of RI…

Experiment 32: Retroactive Inhibition during Subsequent Reading of a Different Syllable List

The aim of this experiment was to investigate whether an interval filled with a second syllable list would lead to lower recall than an unfilled interval. The participant in this study was presented with a list of six syllable pairs and asked to read each pair aloud (emphasizing the second syllable). This was repeated 12 times, after which there appeared an 18 second gap (required for changing the paper on the prism drum). This gap was either followed by a filled delay, in which the participant was presented with a second list of syllable pairs to learn, or an unfilled delay (in which no second syllable list was presented). After 8 minutes the participant was presented with the first syllables of each pair and asked to recall the corresponding second syllables. In the filled condition the participant was also asked to recall 3 of the second list syllables to ensure that she fully attended to this list. This experiment clearly showed that the filled delay period led to a lower recall performance than the unfilled delay period. This is illustrated in Figure 8.

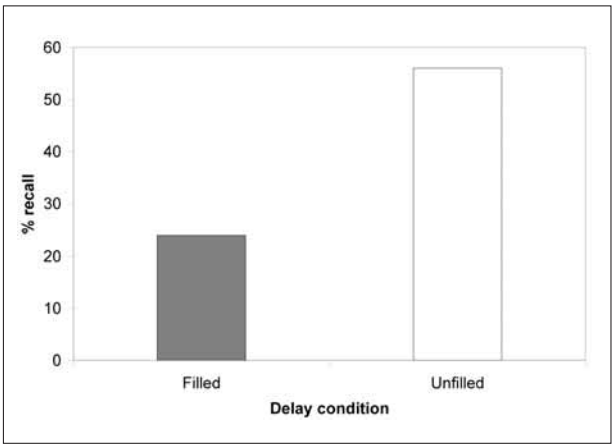

Fig. 8 – *Delayed recall as a function of delay condition.*

Retroactive Interference Material Specificity or General Mental Effort?

Even though Müller and Pilzecker's (1900) first RI study did demonstrate that an interpolated second syllable list impeded recall of the to-be-retained list, it did not elucidate whether the detrimental effect of the interpolated list was directly related to material similarity (i.e., both lists containing nonsense syllables) or to a more general interference (i.e., any subsequent material or task).

It appears that Müller and Pilzecker (1900) may have been working under the material similarity assumption initially as they told participants that they could read a newspaper during the unfilled period in order to avoid thinking about the to-be-recalled syllable lists. They therefore cannot have thought that the reading of new material would have a detrimental effect on later recall. Nevertheless it appeared that many of the participants were skeptical about reading a newspaper during the unfilled period. Dr Behrens in Experiment 32, for example, spontaneously stated that she preferred not to see these newspapers because "the pictures and jokes within these newspapers occupied her intensively meaning that she would forget the newly read syllables" (p. 183). Her preferred method was to walk up and down the room while thinking her own thoughts. She also stated that none of the read syllable lists appeared in consciousness during this time. It appears that such subjective comments may have triggered a curiosity in Müller and Pilzecker (1900) to investigate whether the observed drop in recall was indeed associated with material specific interference or more general mental effort.

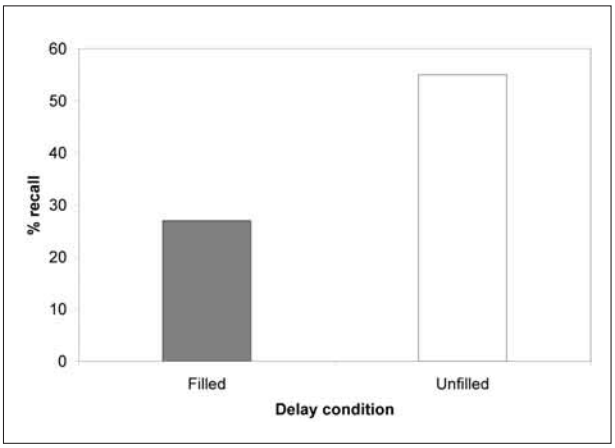

Fig. 9 – *Delayed recall as a function of delay condition.*

Experiment 35:
Retroactive Interference in Experiments Containing Subsequent Pictorial Stimuli

In order to investigate this issue Müller and Pilzecker (1900) tested the same participant as for Experiment 32. The participant was asked to read the nonsense syllable pairs (8 times) and then to look at a set of 3 landscape paintings (10 seconds per picture), which had to be described to the experimenter in detail straight after. The picture task was always brought to an end after 2 minutes (i.e., 30 seconds of observing and 90 seconds of describing) in order to reduce any tiredness at later recall of the main lists.

As in the previous experiment an unfilled delay interval was also included in this study. If the "benefit" following the unfilled delay period had been merely induced by a lack of new syllables (i.e., material specific stimuli) both delay conditions in Experiment 35 should have proven beneficial. However, recall for main lists, which had been followed by the secondary picture task was worse (24% correct) than recall for the main lists that had not been followed by the picture task (56% correct). This is illustrated in Figure 9.

When comparing the two experiments (Experiments 32 and 35) it can be seen that recall was almost identical after the two interpolated tasks (27% correct following syllables and 24% correct following pictures) and that the detrimental effect of the interpolated task cannot be accounted for purely by the similarity of the to be remembered stimuli and the interpolated material. Müller and Pilzecker (1900) consequently used this finding to provide quantitative evidence for their notion of RI being interference by a subsequent *mentally effortful* task (rather than material specific interference).

Insufficient Evidence…

However, even though Müller and Pilzecker (1900) provided some evidence that RI encompasses interference by a subsequent mentally effortful task, they did not try to reject all possible alternative explanations or indeed be more specific when defining *mental exertion*. It is important to highlight that even though the main interpolated task in Experiment 35 involved pictures, the participant had to *verbally* describe the three pictures in the subsequent recall period. Even though such verbal description would have not been highly similar to the to-be-retained syllable pairs, it could have directly interfered with such syllables due to its verbal content (i.e., being identical in modality and verbal coding). For this reason Müller and Pilzecker's (1900) experiment cannot be used to fully reject the notion of material specific interference. In order to elucidate recall decline in the absence of material specific interference one requires an interpolated task, which is absent of any verbal content.

Furthermore both interpolated activities (Experiment 32 and 35) required the participant to learn the interpolated material (syllables or pictures) as recall followed. Hence even though one common factor of the interpolated tasks of Experiment 32 and 35 is "mental effort" they also share an *intentional memory* factor. Even though Müller and Pilzecker's (1900) work clearly illustrates that forgetting is not simply caused by interference by highly similar material, the task of having to learn new material in both interpolated tasks means that this factor, as opposed to (or in addition to) more general mental effort, could have been the culprit. In order to reject such a notion one requires an interpolated task that is mentally effortful yet does not require the participant to intentionally learn any new information of any sort (e.g., looking at the picture but not actively trying to remember it).

One may also question whether merely observing something without actively trying to remember it could be enough to lead to interference (e.g., initial *incidental* encoding of information). Hence another common factor evolves: both tasks contained new material (irrespective of the fact that this material had to be remembered). In order to investigate whether mental effort *per se* can really be the culprit one requires a condition in which the participant has to do an effortful task that does not include *any* new information.

A Modern Müller and Pilzecker-Like Study on the Nature of RI

Müller and Pilzecker's (1900) findings prompted us to investigate material specificity not in terms of interpolated tasks that exactly matched the to-be-retained material (i.e., word lists) but in terms of more general similarity/dissimilarity as well as mental effort.

Method

144 volunteers (59 males, 85 females; mean age = 21.08 years, SD = 1.76; mean years of education = 15.82, SD = 1.65) took part in a between subjects study, in which presented verbal material had to be recalled following one of six delay conditions. Each participant was allocated to one of six groups (c.f., = 24 per group), each of which was presented with the same to-be-retained stimuli. In contrast to Müller and Pilzecker (1900) but in line with some more modern memory research the to-be-retained stimuli on each trial comprised a list of 15 verbally presented nouns (1 per second), which were selected from the MRC Psycholinguistic Database and matched for familiarity, imaginability, concreteness and frequency (word frequency was taken from the British National Corpus). Depending on which group the participant had been assigned to he/she then undertook one of six interpolated tasks during an eight-minute interval (identical to Müller and Pilzecker's delay period).

The experiment was set up to include one purely verbal interpolated task (Group 1) in order to investigate whether interpolated verbal material would result in a different effect than non-verbal material. Participants in this verbal task were required to listen to a radio recording and asked to attend carefully as questions would follow delayed list recall. In order to compare this condition to nonverbal "interference", a visual analog was created (Group 2). As with the verbal task the visual task consisted of real life material (visual clips of scenes around the University campus) that had to be attended to in order to be recalled subsequently after list recall. Hence both tasks contained an intentional memory factor and therefore some level of effort and differed only in modality. A further visual task was included, in which participants were asked to detect differences between pairs of visually presented pictures and to highlight these by circling them (i.e., spot the difference) (Group 3). No new memories had to be formed during this visual attention task. The same applied to a mathematics task, in which participants were given short mathematical problems, and asked to solve them as fast as possible (Group 4). Even though these two tasks did not contain an intentional memory factor, they both contained new meaningful material. Hence the visual attention task most certainly could not interfere due to item similarity but it could interfere due to the introduction of new general information.

Moreover, if RI is characterized by material or modality specific interference or interference by new meaningful material then a task that is solely mentally effortful without containing new meaningful material should not have a detrimental effect on later recall of the lists. In order to test this we utilized a tone detection paradigm (TDP), in which participants were required to detect piano notes of various decibels, which were embedded in brown noise (Group 5). The task was mentally demanding yet did not contain any new meaningful information (c.f., Reitman, 1974).

In order to make any subsequent inferences about the nature of RI, a control condition was also added (Group 6). Participants in this condition were asked to merely sit in a comfortable chair and rest. They were further asked to try not to think of the presented wordlists. All groups were subsequently asked to freely recall as many of the presented words verbally. Each participant performed a total of three presentation-delay-recall trials, each of which consisted of a different wordlist. While the interpolated task remained the same across the three trials (e.g., attending to videos for those assigned to the video group), the stimuli within such task differed across trials (e.g., Video 1, Video 2 and Video 3). The order of the three wordlists and three interpolated stimuli was counterbalanced across participants. Word list presentation, the delay interval and word list recall were all undertaken in the same laboratory and by the same experimenter to minimize any external contextual change.

Results and Discussion

Percentage recall means were computed for every participant. Descriptive data revealed three outliers whose performance fell out-with two standard deviations from the mean; data from these participants were consequently excluded from the main analysis. A one way ANOVA revealed a significant difference in recall following the six interpolated tasks [$F(5, 140) = 5.519$, $p < 0.001$]. Newman-Keuls post-hoc tests (alpha level = 0.05) revealed that this was the result of higher recall following the control condition than any of the five other conditions (i.e., all interference conditions). No differences in recall were found between these five interference conditions (see Figure 10).

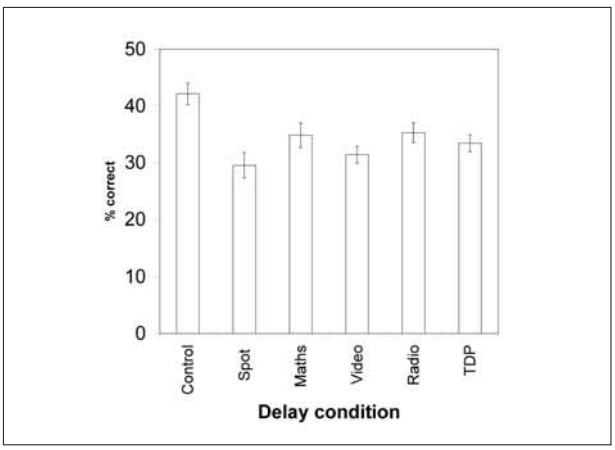

Fig. 10 – *Percent correct recall as a function of delay condition.*

These data allow us the following conclusions:

a) With respect to the criticism of a verbal component embedded in Müller and Pilzecker's (1900) visual RI task, the current study elucidates that a verbal component is *not* necessary for a drop in word list recall to emerge.

b) Mathematics, Spot-the-difference and tone detection interpolated tasks all led to a significant drop in recall when compared to the control condition highlighting that an intentional learning factor is *not* required for the drop in recall to emerge.

c) Most importantly however is the finding that tone detection, the task assumed to be mentally effortful without containing new meaningful material, resulted in a significant drop in recall when compared to the control condition. This provides some evidence that indeed mental effort is *sufficient* to lead to a reduction in delayed recall.

This highly suggests that, as proposed by Müller and Pilzecker more than a century ago, subsequent "diversion" RI (i.e., RI caused by any interpolated mental effort) is a key factor for forgetting to occur.

However as stated above, diversion RI as a theory of forgetting has been largely ignored in modern Psychology. The little that has remained of RI since Müller and Pilzecker (1900) is not greatly akin to the original definition. Indeed, the general consensus on RI in more modern times has undeniably been that this is interference of the-to-be learned material by *learning of new similar material*, see for example the Oxford Dictionary of Psychology: "Impairment of memory for previously learnt information, or performance of a previously learnt task, caused by subsequent learning of similar information or a similar task" (p. 638). Such definition for RI can also be found in Psychology textbooks (e.g., Gleitman et al., 1999; Carlson et al., 2004; Kosslyn and Rosenberg, 2004) and recent articles published in Psychology journals (e.g., Tendolar et al., 1997; Blank, 2002; Mottron et al., 1998).

RI – Item Similarity and/or Mental Effort?

The obvious question is therefore: Where did this theory come from and why has it taken the place of a well proven initial theory? An extensive article on RI by Robinson (1920) suggests that a number of researchers (De Camp, Webb, Brockbank; all cited in Robinson, 1920) began to criticise and dismiss diversion RI theory due to a failure to replicate Müller and Pilzecker (1900) findings of non-specific RI. Instead they began to argue that similarity, previously rejected by Müller and Pilzecker (1900) as an account for RI induced forgetting, was the major cause of forgetting.

Two of these researchers were McGeoch and MacDonald (1931) who studied the effect of similarity between to-be-retained material (10 adjectives) and interpolated stimuli (synonyms, antonyms, unrelated adjectives, syllables and 3 digit numbers) using a modernised version of Müller's memory drum (see Figure 11).

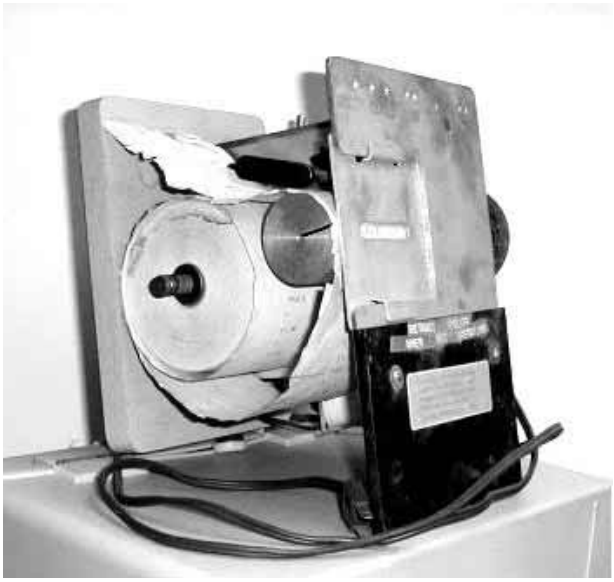

Fig. 11 – *An early apparatus for studying verbal learning at the University of Missouri-Columbia, where John A. McGeoch was Chairman from 1930 to 1935. An electric motor advanced the paper roll at preset intervals so that the current trial's stimuli were visible through the slot-shaped window in the metal plate shown here on the right. McGeoch (1932) advanced the idea that forgetting cannot be attributed to the passage of time*

Unfortunately the authors did not employ an unfilled condition. Even though their control condition was defined as "rest" participants in this study were asked to read "College Humour under instruction to select and mark the three best jokes on each page" (p. 582), a condition more in line with our own verbal interference task than "rest". Nevertheless participants performed better following this interpolated task than following any of the others. Furthermore, it was found that recall following the other conditions declined with increasing similarity between to-be-recalled stimuli and interpolated stimuli in the following manner: 3 digits (38.5%-3.85 adjectives), nonsense syllables (25.8%-2.58 adjectives), unrelated adjectives (21.7%-2.17 adjectives), antonyms (18.3%-1.83 adjectives) and synonyms (12.5%-1.25 adjectives). Further evidence for a similarity-based account of RI was later voiced by Dey (1969) who showed that recall dropped with increasing synonymity ratings between the to-be-retained adjectives and the interpolated adjectives.

However neither McGeoch and McDonald's (1931) nor Dey's (1969) study contained non-material-specific interpolated tasks. Hence while the authors provide strong evidence for interference effects by highly similar interpolated tasks, such evidence cannot be used to reject diversion RI theory. In order to do so the authors would have had to compare recall following a highly similar interpolated task and a more general interpolated

task. It may of course be argued that the "rest" interval, which did lead to higher recall than the similar tasks, was akin to diversion RI and therefore that this provides possible evidence against diversion RI and for similarity RI (i.e., RI by items similar to the to-be-retained material). In fact Robinson (1920) did include similar and general interpolated conditions and found that the similar condition led to the lowest recall while all general interpolated tasks led to higher and equal recall. Robinson's (1920) findings led Skaggs (1925), a supporter of Müller and Pilzecker's (1900) RI theory, to investigate the effect of similarity and diversion RI on delayed recall. Participants in his study were asked to memorize the position of chessmen on a chessboard and were subsequently engaged in one of four conditions: (1) memorizing a new chessman formation (similar), (2) memorizing the positions of non-chess items on the board (intermediate), (3) multiplication (dissimilar) and (4) studying post card pictures of scenery (dissimilar). This was followed by recall of the original chessman positions.

Even though individual data were not clear-cut, group averages suggest a relationship between error rate and degree of similarity of the interpolated task. Closer inspection of the data elucidates that the similar task led to the highest error rate while differences between the intermediate and dissimilar conditions were not substantial. It was further found that performance was better in a syllable recall task when the interpolated task contained reasoning problems (dissimilar) as opposed to new syllables (similar). In light of such findings one can appreciate how diversion RI may have been pushed further and further away from the spotlight. However it is important to note that none of these studies contained an unfilled delayed condition. Participants were asked to read (McGeoch and McDonald, 1931; Robinson, 1920) or talk to the experimenter (Dey, 1969) during the "rest" interval and Skaggs' (1925) study did not contain a rest period at all. Therefore while there is no doubt that similarity effects did emerge in these studies, there is no evidence that similarity is the *only* contributing RI factor of forgetting. Hence it is possible that the more general interpolated tasks also affected recall but with no unfilled condition to compare such recall to, such hypothesis is speculative only. In order to reject diversion RI as an underlying cause of forgetting the authors would have also had to include an unfilled delay interval and shown that recall following the unfilled and "rest" interval was *equally* better than that following the similar conditions.

Nevertheless the findings of similarity effects are certainly interesting with respect to Müller and Pilzecker's (1900) and our findings of diversion RI. The obvious question that emerges in light of such contradictory findings is therefore: If mental effort (and level of mental effort) is the main factor with respect to RI, why did McGeoch and MacDonald's (1931) participants perform worse following highly similar interference stimuli than less similar (yet still verbal) stimuli? Furthermore, if stimulus similarity is indeed a highly important factor with respect to RI then why is there no difference between recall following Müller and Pilzecker's (1900) visual and syllable conditions? Why did our study not lead to poorest recall following the verbal task? Even though this task did not contain wordlists it nevertheless contained verbal information, which should have interfered more with the wordlists than the tone detection or the Spot-the-difference task.

With respect to the former question it may be argued that differences in recall following McGeoch and MacDonald's (1931) various tasks may be explained by differences in mental effort required for the tasks. However it seems unlikely that synonyms require more effort to learn than unrelated adjectives or nonsense syllables, thus making it difficult to explain such findings in terms of diversion RI.

With respect to the second question one may argue that similarity effects are confined to specific processes or material rather than occurring at a modality level. In other words being of the same modality (i.e., wordlists and story) may not be specific enough for similarity interference effects to emerge. Indeed Robinson (1920) provides evidence for such speculation. He found that recall for a list of eight four place numbers was much lower following the learning of another list of eight four place numbers than following multiplication of four place numbers or learning of a string of 32 numbers. In fact the latter tasks led to very similar recall as the other interpolated tasks (e.g., observing pictures or reading a passage of text). This is indeed interesting as it suggests that even highly similar material (4 place digits in the multiplication) or tasks (learning a series of single digits) may not necessarily have a detrimental effect on recall of 4 digit numbers! It appears that as Robinson (1920) puts it "unless the two sets of material are presented in highly similar form there may be no high degree of inhibition" (p. 53).

While such evidence may explain why our verbal interpolated task did not lead to lower recall than the nonverbal tasks, it does not explain why our verbal task did nevertheless lead to lower delayed recall than the control task and why Müller and Pilzecker's (1900) verbal interpolated task, which was highly similar to the to-be-retained material and its presentation, did not interfere more with recall than their visual task. As the visual task did contain verbal content thus making it more similar to the syllable interpolated task in terms of modality a possible argument could be that both conditions interfered due to being similar to the to-be-retained information. However such hypothesis appears very unlikely in light of the above reported

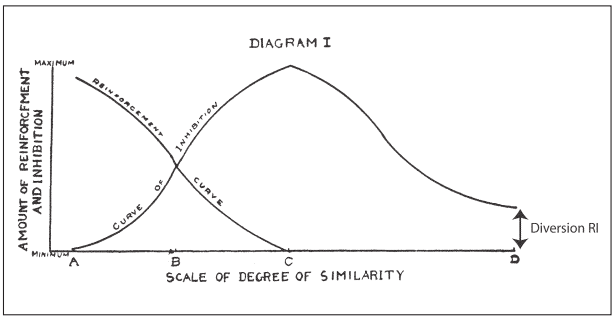

Fig. 12 – *Skaggs' (1925) diagram of reinforcement and inhibition.*

Caption quoted from Skaggs (1925): "Explanatory Note – The above diagram is merely theoretical in its outline. Possibly the curves may be drawn with some mathematical precision in the future. The scale on the left vertical represents the amount of reinforcement and retroaction – two opposed processes. The horizontal scale represents the degree of similarity between the original learning and the interpolated work. Beginning at A where learning and work are identical, as we go to the right there is greater and greater dissimilarity until at D the two are as dissimilar in content and method as possible. At A inhibition is at a minimum and reinforcement at a maximum (mere repetition); at C the situation is reversed. At D the inhibition curve has fallen but never to the original minimum" (p. 32).

work by Robinson (1920) who would certainly deem the verbal content within the visual task "dissimilar". It appears then that it is virtually impossible to explain diversion RI in terms of similarity RI or vice versa which suggests that both types may in fact affect memory.

In fact Skaggs (1925), also confronted with the contradictory finding of both similarity and diversion RI, proposed an interesting theory of RI that encompasses both similarity *and* diversion RI (see Figure 12): He states that when interpolated material is identical or highly similar to the to-be-retained material there is no inhibition but repetition and therefore reinforcement (see Figure 12). He goes on to theorise that as the interpolated material decreases in degree of similarity so do the reinforcement factors while the interfering factors increase. This would occur until interference reaches a maximum, after which interference decreases. Skaggs (1925) stated that it is after this maximum that "we can say that the more dissimilar the materials the LESS the detrimental influence" (p. 57). It is however Skaggs' (1925) last point that is the most crucial with respect to the similarity – general effort "debate". Skaggs (1925) stated: "However, the curve of detrimental influence never reaches zero because after the work and learning are as different as can possibly be made there is still a demanding influence exerted by work" (p. 57).

Skaggs' (1925) research and theory therefore suggests that similarity AND general mental effort both can have an effect on subsequent recall and that both can in fact go hand in hand as opposed to being two mutually exclusive entities and theories. Indeed Skaggs (1925) makes the important point that any interpolated material/task, be it mental effort per se or similar material, causes diversion RI, and that similar material simply adds further interference (i.e., similarity RI) due to its similarity with the to-be-retained material.

In fact as will become more evident during the next paragraphs it appears that these two forms of RI may in actual fact affect two different cognitive memory processes.

Which Processes does RI Affect?

Müller and Pilzecker's (1900) Research into RI and Consolidation

Müller and Pilzecker (1900) not only investigated the nature of RI but also sought to explain *how* RI led to forgetting. Their early theories of consolidation led Müller and Pilzecker (1900) to make the prediction that "the associations of a read syllable list are less and less affected by the reading of a subsequent syllable list the later the reading of the subsequent list occurs" (p. 184).

Experiment 34: Retroactive Inhibition Increases in Strength as the Proximity between Main List and Second List Decreases

In order to test such hypothesis Müller and Pilzecker (1900) presented a participant with a list of syllables. This was followed by one of two delay intervals and subsequent delayed recall. The crucial difference between the two delay interval conditions was the onset time of the reading of the second syllable list, which was either presented after 17 seconds (time required to change the drum) or 6 minutes after presentation. As predicted it was found that recall was higher following the late onset RI condition (after 6 minutes) than the immediate onset RI condition (49% and 28% respectively). This led Müller and Pilzecker (1900) to conclude that the first syllable list could be strengthened (i.e., consolidated) during the six minute interval, resulting in the syllable list being less susceptible to the interfering effects of the second syllable list.

Skaggs (1925) provided further evidence for such a *temporal gradient of RI* (Wixted, 2004) following a more extensive experiment, which included 4 conditions, in which a period of "simple equation problems" (p. 21) was interpolated at varying onset times within a five minute delay interval. The to-be-retained information in this case was a reconstruction test, in which the participant was presented with a chess board containing five chessmen, whose positions the participant had to remember during the recall period.

Skaggs' (1925) data revealed that the group average number of errors was highest following immediate onset of the algebra task and levelled thereafter (i.e., even one minute of rest prior to RI was sufficient for the number of errors to drop

largely) thus supporting Müller and Pilzecker's (1900) notion of a detrimental effect of (diversion) RI on consolidation and their perseveration theory.

Opposing Views
Consolidation versus the Transfer Theory

Such notion was challenged by opponents of the perseveration theory such as McGeoch and Nolen (1933) and Robinson (1920) (see Wixted, 2004 for a full review) who found that the detrimental effects of RI were identical whether RI was positioned immediately after item presentation or immediately before item recall. These researchers argued that such findings supported the so-called transfer theory of retroaction. McGeoch and Nolen (1933) provided the following definition of transfer theory: "The theory holds that the decrement in measurable retention which follows interpolated learning occurs because of a confusion between the original and interpolated materials, a confusion which results from the transfer of parts or aspects of one to the other" (p. 414). The same authors also state that the theory is based on a major requirement, which is that "the interpolated material be learned before the original material has been forgotten and that it bear at least a minimum similarity to the original material" (p. 414).

However, Skaggs (1933) argued that the studies leading to such a theory were flawed in that they contained inappropriate rest intervals e.g. looking at pictures or counting beans which he believes introduces "a complicating mental activity which is far from the state of passivity demanded by a crucial test of temporal position and the perseveration view" (p. 413). Indeed considering that the delay intervals were long [23-24 hours in McGeoch and Nolen's (1933) case] and anything but unfilled (i.e., introducing enduring RI) in most cases, it is not surprising that recall was equally bad following immediate or delayed similarity RI.

A further criticism voiced by Skaggs (1933) is the inclusion of highly similar to-be-retained and interference material [e.g., two mazes in McGeoch and Nolen's (1933) study] and the presentation of highly similar interference material immediately prior to recall of the to-be-retained stimuli. Having considered similarity based RI himself in his 1925 paper, Skaggs (1933) strongly argued that one would expect that the learning of very similar information immediately prior to recall of A would "introduce confusion into the recall of A" (p. 412). He went on to make an important point namely that "this would not be retroactive inhibition at all but a simple case of *reproductive inhibition*" (p. 412), hence a case of inhibition at retrieval as opposed to consolidation. Indeed similar material is likely to lead to the same amount of similarity RI if placed at the very start and the very end of the delay interval for this very reason. Hence while such material is likely to interfere with consolidation and retrieval when placed immediately following presentation of the to-be-retained information, it is also likely to interfere with the retrieval of such information if placed immediately prior to recall. This in turn would overshadow at least some of the benefits of delayed RI.

Skaggs (1933) extends his above-mentioned theory of coexisting similarity and diversion RI (Skaggs, 1925) and makes the crucial proposition that these two forms of RI act at different stages in the memory process. He stated: "There are two factors causing what is now called retroactive inhibitory effects. In one case a strong mental-neural activity cuts in an organized and on-going mental-neural process, a process of neural inertia. This is true for retroactive inhibition since a second activity interferes with a fixing process on the part of an earlier initiated activity. There is considerable (at least indirect) evidence for such fixating processes. In the other case there is a matter of the establishment of wrong associative tendencies which operate at the time of recall. This is due to the mixture of like and unlike elements in the two learning situations. Whether we wish to call the detrimental influence on later recall retroactive inhibition or plain reproductive inhibition depends entirely on whether the original learning is actually weakened as such at the time of the interpolated activity or whether it is a matter of confusion and blocking in the actual recall" (p. 413). This statement forms a plausible answer to both above raised questions, namely that of similarity versus mental effort and that of the cognitive processes affected by RI.

Similarity RI – Akin to PI?

In light of Skaggs' (1933) theory it is interesting to note the analogy between PI and similarity RI. Both appear to affect memory at the level of retrieval. More specifically they both seem to be the result of competition at retrieval due to the high resemblance in material type and retrieval and contextual cues (Mensink and Raajmakers, 1988) of the to-be-retained and interfering stimuli. Furthermore, both appear to occur much more frequently in the laboratory than in everyday life. Similarity RI may therefore be much more akin to PI than to diversion RI, which appears to be more closely related to everyday forgetting. This raises some interesting questions in relation to the underlying neural correlates of RI. Research has elucidated a particular susceptibility to PI in patients with frontal lesions (e.g., Shimamura et al., 1995; Baldo and Shimamura, 2002) suggesting a role of the frontal lobes in dealing with PI. The question arises whether similarity RI can also be traced back to faulty frontal lobe activity during retrieval of the to-be-retained information. Shimamura et al. (1995) tentatively suggest

possible (similarity based) effects of RI in their frontal lobe patients. However, Tendolkar et al. (1997) found no prefrontal activity in their (similarity) RI ERP experiment. Thus future fMRI and patient studies are required to provide answers to such questions.

Retroactive Interference as a Global Cause of Forgetting?

A related question is whether and to what extent interference also affects those amnesic patients *without* frontal lobe damage.

There are several cognitive hypotheses as to why patients with anterograde amnesia show poor long-term memory for events and stimuli experienced only moments before. Such hypotheses include for example faulty encoding, accelerated forgetting, faulty consolidation and faulty retrieval (see Kopelman, 2002, for a thorough review) but have never actually included RI. However, just as is the case for the neurologically intact population, the time between learning and recall in the amnesic population is invariably filled with other tasks/materials in both everyday life as well as in clinical memory assessment (e.g., the Wechsler Memory Scale and the Rivermead Behavioural Memory Test). The question therefore arises whether such tasks/materials may in fact play a role in the severe forgetting by interfering with the to-be-retained information.

Mayes et al. (1994) did include an RI factor in their study on forgetting in amnesia. However their definition of RI appears to resemble similarity-RI more than diversion RI. Participants in their study were asked to remember sets of ten photos of faces. This was then followed by the Interference condition, during which the participants were presented with a further set of photos of faces or the standard condition, during which the participants were "engaged in conversation and other activities (not involving faces)" (p. 549). The authors found no significant group × condition interaction leading them to conclude that "there was no evidence that the amnesic group as a whole was more susceptible to the type of sustained retroactive interference that was built into the present experimental design" (p. 558). While such a study may provide evidence that this sample of amnesiacs does not show higher susceptibility to similarity-RI than controls, it does not reject the possibility that this sample was more susceptible to diversion RI than the control group. In fact there was a group main effect (higher delayed recall for the controls) and while this may have occurred due to several factors, higher susceptibility to diversion RI could have been the culprit or at least one of the culprits. As with the neurologically intact population the only method by which such a question can be addressed is to compare recall

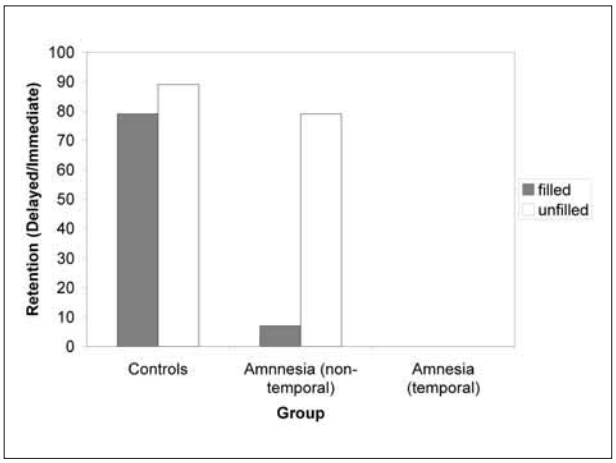

Fig. 13 – *Prose recall in focal brain injury patients. Proportion retention as a function of delay condition and group.*

following a filled interval with that following an unfilled interval. This was the purpose of some recent studies by Cowan et al. (2004) and Della Sala et al. (2005).

Both these studies revealed that patients suffering from anterograde amnesia as a consequence of mild cognitive impairment (MCI) or focal brain damage (that did not encroach upon the temporal lobes) showed significantly better recall of a prose passage/word list after an unfilled delay period (60 minutes/10 minutes) than a filled delay period (doing various psychometric tests, none of which contained material similar to that of the prose/word list or required learning of new material) (see Figures 13 and 14). If time were the only factor no such differences should have been observed following the two conditions as time itself was constant. It should further be noted that these patients were typically unable to remember anything after 30 seconds and hence that the improvement observed in these experiments by minimising RI was indeed remarkable.

These results demonstrate that at least some (non-temporal lobe) anterograde amnesia patients did not inevitably forget the information within

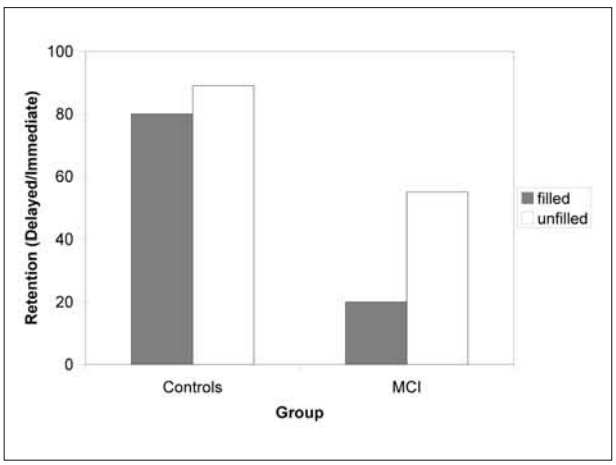

Fig. 14 – *Prose recall in MCI patients. Proportion retention as a function of delay condition and group.*

seconds but that they could retain it for at least one hour under the right conditions (i.e., under minimal 'diversion' RI). Thus these experiments suggest that such patients may be highly susceptible to RI.

Cognitive Processes Underlying the Benefit of Minimal Diversion RI. Some Possible Candidates

The aforementioned studies on diversion RI and forgetting highly suggest that both neurologically intact people and a number of amnesiacs perform better at delayed recall of to-be-retained material when the delay interval is unfilled (i.e., minimal RI) than when it is filled with non-similar, yet mentally effortful and thus diversion RI-inducing material. Thus both populations show a *benefit of minimal diversion RI*. It is important to note that in order to minimise diversion RI, both diversion and similarity RI have to be reduced as any interpolated material/task requires mental effort and hence causes diversion RI. It is highly unlikely however that such reduction in similarity RI during minimal diversion RI can account for the specific *benefit* of minimal diversion RI (i.e., the specific difference in delayed recall following minimal diversion RI and pure diversion RI) as similarity RI is also reduced during pure diversion RI (i.e., when the interpolated material/task is unrelated to the to-be-retained material). In other words, any benefit of minimising similarity RI is already accounted for when comparing delayed recall following pure diversion RI and minimal diversion RI. It must therefore be the reduction in interpolated mental effort and thus the reduction in diversion RI that leads to the observed substantial benefit of minimal diversion RI.

The cognitive processes that underlie such benefit remain to be established. The possibilities we will discuss, both on the basis of the historical research and on the basis of our recent studies on amnesia, are as follows: (1) Minimizing RI may allow the information to persist in some sort of short-term memory. It could be the conventional time-limited concept of short-term memory (Baddeley and Hitch, 1974; Baddeley, 1986), or it could be the focus of attention (Cowan, 2001), or it could be memory for the most recent items; (2) Minimizing RI may allow the material to be consolidated better in long-term memory; (3) Minimizing RI may allow the material to be retrieved better from long-term memory because of an absence of RI material competing for retrieval with the to-be-retrieved stimuli.

Uninterrupted Short. Term Memory Maintenance?

The benefit of minimal RI could underlie uninterrupted short-term memory maintenance of the to-be-retained stimuli either within a time-or a capacity limited short-term mechanism. These two possibilities will be discussed separately in the subsequent paragraph.

Uninterrupted Rehearsal within Time Limited Working Memory?

An obvious candidate for increased delayed recall following an unfilled interval is conscious rehearsal of the to-be-retained material within working memory (Logie and D'Esposito, in press). Hence, neurologically intact participants and anterograde amnesia patients alike could in theory consciously rehearse to the to-be-retained information during the unfilled delay (Scoville and Milner, 1957; Milner, 1968; Odgen, 1996). There is however a large pool of evidence against this working memory rehearsal alternative.

Neurologically intact population. With respect to the neurologically intact population it is important to go back to Müller and Pilzecker's (1900) pioneer research. In their conclusions on RI Müller and Pilzecker (1900) argue that the effects of RI could not have emerged as a consequence of the participants not being able to think of the stimuli. They draw evidence from the fact that participants rarely reported appearance of the stimuli in consciousness. Furthermore they stated that RI was also found when using the savings method and that appearance of stimuli in consciousness would not lead to any beneficial effect when using such a method. Indeed the participants in these experiments (Experiments 36 and 37) were asked to learn List 1, which was followed by a rest period of 4 minutes. The participant was subsequently presented with List 2, which was immediately followed by another list. This sequence was then repeated. Subsequently the participant rested for 10 minutes prior to relearning List 1 and List 2 (errorless). Less repetitions were required for List 1 than List 2. Müller and Pilzecker (1900) state that such benefit cannot have emerged due to rehearsal as any rehearsal of List 1 would have been followed by further trials before relearning.

Further evidence against a rehearsal account comes from Skaggs (1925) who was also very aware of such alternative explanation as can be gleaned from his comment: "It may be claimed that the advantage of the rest interval lay in the very fact, namely, that during the rest the subject repeated the learning whereas during the work he could not. The point is a very crucial one" (p. 13). However, Skaggs (1925) tested both naïve participants as well as a small group or participants who had been trained "in the art of giving keen and thorough introspections and were able to adjust themselves to the conditions of the experiment" (p. 1). In order to tackle the rehearsal hypothesis Skaggs (1925) considered the data of the trained

participants and analysed only the trials from those rest intervals that "were free from any consciousness of the original learning, with the exception of a short after-image which was always present" (p. 13). The results were in line with his previous findings of a substantial benefit of minimal RI therefore providing further evidence that the difference in recall between the filled and unfilled conditions cannot be attributed to conscious rehearsal of the material during the delay period.

Anterograde amnesiac patients. Turning to the amnesic group, there are three main sources of evidence that speak against the conscious rehearsal account: Firstly the initial delayed recall came as surprise, meaning that participants had little if no incentive to consciously rehearse the material for up to an hour, yet did not lead to poorer recall than later trials. Furthermore, the to-be-retained information in Della Sala et al.'s (2005) study and Cowan et al.'s (2004) second experiment was a prose passage consisting of a much larger quantity of information than can be rehearsed within the traditional time limited working memory. If rehearsal were the only cognitive process underlying the benefit, patients should have only recalled as much information as can be actively rehearsed in working memory. Finally, two patients were observed to be sleeping (identified by loud snoring, a state in which conscious rehearsal would be carried out with some difficulty) during some hour-long retention intervals with minimal interference, yet benefited from minimal interference as much as on other trials, and as much as other patients did.

Uninterrupted Capacity Limited Short-Term Retention?

There is the possibility of a short-term memory mechanism that can hold only a small amount of information, which is displaced by subsequent stimulus inputs, or even by the retrieval of competing thoughts (Baddeley, 2001; Cowan, 2001).

Cowan (2001) suggested that this type of information storage occurred in the focus of attention, and Baddeley (2000, 2001) has not clearly addressed the attention requirements of the mechanism of this type he introduced, the "episodic buffer".

Neurologically intact population. As discussed above there is strong evidence that improvement in delayed recall following minimal RI is not dependent upon constant attention towards the to-be-retained material in neurologically intact participants (c.f., Müller and Pilzecker, 1900; Skaggs, 1925). Hence, if such improvement in this population did underlie the workings of a capacity limited short-term store, such store would have to be in the form of a mechanism independent from attention during retention, which would conflict with the theoretical mechanism that Cowan (2001) suggested for limited-capacity storage.

Moreover, while the inclusion of RI does lead to a decrease in delayed recall in the neurologically intact population, performance does not drop to floor as is the case with the amnesiacs. As to-be-retained material would be displaced by RI if it were retained within a capacity limited short-term store, it is unlikely that such mechanism can account for the retention of the to-be-retained material in the RI condition. While in turn it is theoretically possible that the improved retention following *minimal* RI could underlie a capacity-limited short-term store (which would have to be independent from attention), it appears much more plausible that such minimal RI retention would underlie the same mechanism as does retention following RI.

Anterograde amnesiacs. It appears that the amnesiacs who benefited from minimal RI were able to do so without having to attend to the to-be-retained material (i.e., during 'surprise' and 'sleep'). As already discussed with respect to the neurologically intact population such finding is at odds with the capacity limited short-term retention mechanism proposed by Cowan (2001).

It is possible that information is maintained within a temporary retention buffer that requires attention for the entry of information, but not for its maintenance. Therefore, once within the buffer, information would be maintained automatically without the need for attention until distracting material or tasks (i.e., RI) entered the buffer. The benefit would therefore occur due to a lack of displacing material entering such temporary retention buffer.

Evidence for the existence of such buffer would indeed be highly interesting as the period of temporary retention of information, up to an hour or more, is far beyond what has been proposed previously for temporary memory storage mechanisms.

Uninterrupted Long-Term Memory Consolidation?

Neurologically Intact Population

As discussed above, Müller and Pilzecker (1900) proposed that the unfilled period allowed uninterrupted consolidation to take place in neurologically intact people. Evidence for this account comes from their own and Skaggs' (1925) findings of better recall following late onset RI than immediate onset RI. In line with such evidence Wixted (2004) theorises that resources are limited and that new learning requires resources that are simultaneously required by the consolidation of the to-be-retained material. In light of the above evidence and theories it seems highly probable that uninterrupted consolidation is a key

candidate for explaining the benefit of minimal diversion RI in neurologically intact people.

Anterograde Amnesia Patients

It is possible that there may also be some long-term memory consolidation taking place in the amnesic patients who benefited with no RI. To-be-retained material may be in the focus of attention long enough for consolidation mechanisms to process it. RI might cause a shift of attention which results in other interfering material also being entered into such consolidation mechanism and thus preventing consolidation of the materials to be remembered. In the absence of RI, though, this might not be a problem; the consolidation mechanism might then successfully retain the material presented last, except in patients with sufficiently severe damage to such mechanism. Further research involving multiple delayed recall periods will elucidate whether or not minimal RI allows for consolidation of the to-be-retained material.

Uninterrupted Retrieval?

Neurologically Intact Population

Some researchers argue that interference-induced forgetting occurs during retrieval of to-be-retained information (e.g., McGeoch and Nolen, 1933; Anderson and Bjork, 1994; Anderson, 2003). However it appears that similarity in to-be-retained and interpolated materials is a prerequisite for RI to occur at retrieval. Hence, it is assumed that similarity in material (Skaggs, 1933; McGeoch and Nolen, 1933) as well as similarity in retrieval cues, such as explicit retrieval cues (i.e., 'A' in A-B, A-C paradigms) and contextual cues (Mensink and Raajmakers, 1988; Anderson and Bjork, 1994) all render the to-be-retained and interpolated material highly similar, thus leading to competition for retrieval when the participant is asked to recall the to-be-retained material. Minimal RI should hence lead to a lack of other items competing for retrieval and therefore to improved recall of the to-be-retained material.

While "uninterrupted" retrieval is likely to account for the "benefit" of minimal *similarity* RI (i.e., higher delayed recall following mental effort than similar material, c.f. McGeoch and McDonald 1931; Robinson,1920; Dey, 1969; Skaggs, 1925), it is unlikely to account for any further improvement caused by minimal RI (i.e., the benefit of minimal *diversion RI* found by Müller and Pizecker, 1900, Skaggs, 1925 and ourselves) as neither minimal RI nor mental effort contain material that is similar to the to-be-retained material.

It is nevertheless possible that mental effort may interfere at retrieval due to becoming associated with the retrieval context of the to-be-retained material. However it is highly unlikely that such factor could account for all of the difference in delayed recall following minimal RI and diversion RI. Tone detection, for example, contains no similar or even meaningful material. Hence the retrieval context could only cue a more general memory of the task itself. While such memory may compete for retrieval with the to-be-retained material to some extent, the experimenter's request for the participant to recall the previous world list should provide stronger retrieval cues for the to-be-retained material than any memories of tone detection. Thus, it appears somewhat unlikely that the observed drop in delayed recall following tone detection can be solely accounted for by such contextual effects.

This prediction is supported by Watkins et al. (1973) who elucidated that delayed recall was much poorer when tones presented during the delay had to be attended to than when they could be ignored, demonstrating that after any effects of the actual interference stimuli and their associations with the retrieval context have been accounted for, mental effort still leads to a reduction in delayed recall. Hence, while minimising similarity RI (including any items forming associations with the retrieval context of the to-be-retained material) and thus interference at retrieval undoubtedly aids memory in neurologically intact people, it cannot wholly explain the benefit of minimal RI relative to diversion RI elucidated in the above reported diversion RI studies. Further research is required to examine the relative benefits gained by minimising similarity RI and diversion RI.

Anterograde Amnesia Patients

A similar argument can be raised for the anterograde amnesia group. Even though the RI research on anterograde amnesia patients (Cowan et al., 2004; Della Sala et al., 2005) has only included one type of interpolated activity (versus none), one can reject the possibility that the benefit of minimal interference was solely due to a lack of similar material. If this were the case the patients should have benefited following the interpolated intervals as well, as these did not contain any material that was highly similar in content to the to-be-retained stimuli. However such "benefit" was not observed which leaves little evidence for a retrieval account of the benefit seen in the patients. It is possibly that some of the benefit could have resulted due to a lack of additional material associated with the retrieval context. Nonetheless, it is very unlikely that such factor could explain all or a large part of the benefit of minimal diversion RI as this would imply a large susceptibility to interference at retrieval by items cued by the same contextual retrieval cues as to-be-retained material. However such deficit would mean (a) that memory should be intact for materials with contextual

retrieval cues not shared by other items and (b) that the presence of such a specific context-related retrieval deficit should also manifest itself in retrieval of retrograde memory. However the patients benefiting from minimal RI in the studies by Cowan et al. (2004) and Della Sala et al. (2005) had global anterograde amnesia with spared retrograde memory.

In light of the above discussion it appears somewhat unlikely that the referred-to amnesiacs showed a specific susceptibility to interference at retrieval and therefore that their "benefit" could be traced back to "uninterrupted" retrieval processes. However, additional work is under way to test such hypothesis more thoroughly.

Bringing Together Old and New

Despite the common negligence of Müller and Pilzecker's (1900) original RI research and definition (i.e., diversion RI) in Psychology today, it is highly evident from the above review and research that such factor does play a considerable role in human memory. While such "rediscovery" of RI does not signify the demise of similarity RI, it does call for a revision of the current RI theory.

We propose such a potential revision that integrates both diversion as well as similarity RI in neurologically intact people as well as anterograde amnesiacs. We suggest that both diversion and similarity RI exist (as proposed by Skaggs in 1925) but that they differ (a) in terms of the cognitive processes they affect (as proposed by Skaggs in 1933) as well as (b) potentially in terms of the neural substrates they have an effect on (see Figure 15).

We propose, on the basis of the old and new research reviewed above, that in neurologically intact people diversion RI affects the consolidation stage of memory. Given the frequent association of consolidation and temporal lobe structures (i.e., the hippocampus) we further suggest that such interference occurs within the temporal lobe.

Similarity RI, on the other hand is likely to affect retrieval processes. Due to its close resemblance to PI and the association between PI and frontal lobe activity, we tentatively propose that similarity RI affects frontal lobe processes, though this warrants further research. Furthermore, while diversion RI can occur independently of similarity RI, the reverse does not seem plausible. Hence, any interpolated material/task, including similar material, causes diversion RI and will therefore affect consolidation. The memory decrement induced by interpolation of similar material is thus likely to be the cause of an additive effect of diversion RI and similarity RI, and hence the cause of interference at the consolidation and retrieval stage. Therefore, while minimising similarity RI should only allow for

Picture in low resolution 130%

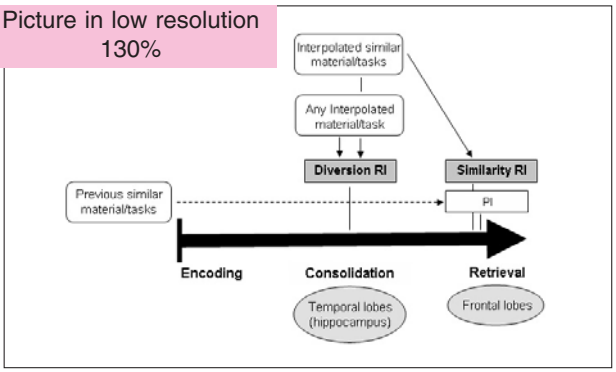

Fig. 15 – *Long-term memory processes affected by interference. The above diagram is an illustration of the potential effects of diversion RI and similarity RI on the normal memory process. The horizontal thick arrow depicts the cognitive processing of a to-be-retained stimulus from its initial encoding to its storage and last to its retrieval. Material/activity interpolated between the encoding and retrieval of the stimulus has a detrimental effect at delayed recall of this stimulus caused by interference at its storage and/or retrieval stage. Any interpolated material/activity (diversion RI) affects the storage stage (predicted to underlie temporal lobe processes) of the to-be-retained stimulus by interfering with its consolidation process. Interpolated material highly similar to the to-be-retained stimuli further leads to similarity RI and hence also affects retrieval (predicted to underlie frontal lobe processes) of the to-be-retained material (as does PI, caused by similar material occurring prior to encoding of the to-be-retained material).*

uninterrupted retrieval, minimising all RI should allow for both uninterrupted consolidation and retrieval. Further similarity RI studies based on Müller and Pilzecker's (1900) delayed RI paradigm may allow for a teasing apart of the similarity and diversion RI effects caused by similar interpolated material (i.e., due to a reduced susceptibility to diversion RI when interpolation of subsequent material is delayed) and hence an elucidation of the true magnitude of the actual similarity RI effect.

We further propose that the memory deficits in at least some amnesiacs may be the result of a severely heightened susceptibility to the diversion and/or similarity RI (and PI) experienced to a mild extent by all neurologically intact people. Patients with specific damage to the retrieval system (as may be the case in patients with lesions to the frontal lobes) may thus present with a severely heightened susceptibility to similarity RI and PI and "normal" susceptibility to diversion RI. On the other hand, patients with specific damage to the storage processes or to the mechanisms that feed into such processes (as appears to be the case for the patients described by Cowan et al., 2004 and Della Sala et al., 2005) may present with severely heightened susceptibility to diversion RI.

It appears from Cowan et al.'s (2004) research that an intact temporal lobe is required for amnesic patients to benefit from minimal RI. With respect to the above discussion on potential cognitive processes underlying the benefit in the amnesic group, such notion would imply that parts of such undamaged temporal lobe could serve as (a) a capacity limited retention buffer (which would still be intact in patients who would be no longer able to

consolidate new memories) or (b) a consolidation system (as it is assumed to be in neurologically intact people). If the benefit in the amnesiacs could be explained by the former, patients would not in actual fact have an "increased" susceptibility to diversion RI. Hence they would "simply" present with impaired consolidation and spared capacity limited STM; i.e., the effects of RI would underlie the "normal" limits of a functioning capacity limited STM mechanism.

If the latter could explain the benefit, a main characteristic of this type of amnesia could be a highly raised susceptibility to the diversion RI. The requirement of an intact temporal lobe would thus most likely indicate the requirement of a consolidation system for emergence of a benefit in this patient group. The data by Cowan et al. (2004) suggests that in such case the actual cause of the susceptibility to diversion RI would most probably underlie the patients' non-temporal lesions. It is for example possible that such non-temporal structures are required for the filtering and structured input of to-be-retained information into the consolidation mechanism within the temporal lobe. Damage to such structures may thus lead to an overload of information into such system leading to no consolidation taking place. In the absence of RI however the damage of such filtering mechanisms would not matter, as only the to-be-retained material would be entered into the temporal lobe system.

The finding of a benefit in MCI patients with some hippocampal atrophy further indicates that less extensive damage to the consolidation system itself may also lead to heightened susceptibility to diversion RI (possibly because such damage renders the system unable to process more than a few stimuli at a time).

Future research will elucidate whether or not the patients who benefit from minimal RI do so due to preserved consolidation or due to the use of a capacity limited STM buffer. It is even plausible that both types of "benefit" exist.

Conclusion

The old and recent research reviewed in this paper together with the new data reported suggest that forgetting is at least partially caused by "diversion" RI in both neurologically intact people as well as patients with non-temporal anterograde amnesia. These findings are relevant for several reasons: Firstly they elucidate that RI does play a role in (everyday) forgetting as originally proposed by Müller and Pilzecker (1900). Secondly these findings provide evidence that similarity, which is most frequently associated with RI nowadays, is not a "requirement" for RI effects to emerge, but that mental effort per se [Müller and Pilzecker's (1900) original definition] can cause considerable disruption to everyday memory. Furthermore Müller and Pilzecker's (1900) as well as Skaggs' (1925, 1933) research strongly suggests that such disruption by RI takes place at the consolidation level, another fact frequently ignored in modern psychology , which places RI at the retrieval stage. We finally propose that (as postulated by Skaggs, 1933) there are two types of RI, diversion and similarity RI, the former affecting the consolidation and the latter the retrieval processes.

In conclusion the arguments raised in this paper indicate that Müller and Pilzecker's (1900) research and theories are not only of historical importance, but also valuable for current research on healthy and pathological forgetting alike.

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