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Random noun generation in younger and older adults

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We examined age-related changes of executive functions by means of random noun generation. Consistent with previous observations on random letter generation, older participants produced more prepotent responses than younger ones. In the case of random noun generation, prepotent responses are nouns of the same category as the preceding noun. In contrast to previous observations, older participants exhibited stronger repetition avoidance and a stronger tendency toward local evenness—that is, toward equal frequencies of the alternative responses even in short subsequences. These data suggest that at higher adult age inhibition of prepotent responses is impaired. In addition, strategic attentional processes of response selection are strengthened, in particular the application of a heuristic for randomness. In this sense response selection is more controlled in older than in younger adults.

Keywords: Executive functions; Random generation; Ageing.

Among the most conspicuous age-related changes of cognitive functions are those of working memory (e.g., Grady & Craik, 2000; Smith, 1996). Whereas processes of encoding and maintenance as assessed by simple span tasks, for example, are only moderately affected, the impairment of executive functions is more severe (e.g., Daigneault & Braun, 1993; Wingfield, Stine, Lahar, & Aberdeen, 1988). This pattern of findings is consistent with the observation that ageing has particularly strong effects on those cognitive functions that are critically dependent on the integrity of the frontal lobes (cf. Hedden & Gabriele, 2004; Raz, Gunning-Dixon, Head, Dupuis, & Acker, 1998; West, 1996). However, executive functions are not a homogeneous set. Baddeley (1996) used the metaphor of an "executive committee" to emphasize this fact. Thus, age-related changes of different kinds of executive functions might differ. The purpose of the present study is to contribute to the identification of executive functions that are more or less vulnerable to age-related declines.

One of the tasks used to assess executive functions is random generation (cf. Baddeley, 1996; Baddeley, Emslie, Kolodny, & Duncan, 1998;

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Towse, 1998). In terms of activated brain regions, imaging studies have revealed prefrontal involvement in random number generation (e.g., Itagaki, Niwa, Itoh, & Momose, 1995; Jahanshahi, Dirnberger, Fuller, & Frith, 1997). Transcranial magnetic stimulation of the dorsolateral prefrontal cortex has been shown to impair performance (Jahanshahi & Dirnberger, 1999; Jahanshahi et al., 1998), and frontal-lobe lesions are associated with poorer performance as well (Spatt & Goldenberg, 1993). However, random generation has also been shown to suffer from diverse neuropsychological conditions, which may not always embrace frontal-lobe dysfunctions (cf. Brugger, Monsch, Salmon, & Butters, 1996, for a review).

Random generation has received sporadic attention for decades in experimental psychology (for reviews, see Brugger, 1997; Nickerson, 2002; Tune, 1964; Wagenaar, 1972). By way of clarifying the major influences on performance, this research constrains process models. At first glance randomization performance appears quite complex, partly because of the many dependent variables that can be computed. Still a rather simple model captures major experimental findings. This model posits two concurrent processes of response selection, which are similar to the supervisory attentional system and the contention scheduling in the theory of Norman and Shallice (1980, 1986). Here we refer to these processes as attentional and nonattentional response selection, respectively, or attentional and nonattentional control for short.

Attentional selection of responses requires the application of a rule (or a set of rules) that serves the goal of producing a random sequence. Such rules should conform to a concept of randomness that is applied not only to the generation of random sequences, but also to the judgement of the randomness of perceived sequences. To characterize this concept, different but often similar proposals have been made (cf. Falk & Konold, 1997). A quite simple criterion that has been suggested is “evenness” (Spatt & Goldenberg, 1993) or “local representativeness” (Kahneman & Tversky, 1972; Rapoport & Budescu, 1997). According to this criterion, sequences are generated randomly (or judged as random) in which the relative frequencies of the alternative responses match the target probabilities as closely as possible within subsequences of limited lengths. The criterion is restricted to a single basic feature of random sequences—namely, the expected frequencies of the response alternatives. This feature, however, is conceived not only as a long-run characteristic of random sequences, but also as a short-run characteristic.

Application of the criterion of local representativeness results in characteristic deviations of human-generated random sequences from those generated by a random process, and it also results in judgements of sequences as random that deviate from random sequences in certain ways (cf. Rapoport & Budescu, 1997). The most characteristic and ubiquitous deviation is called negative recency or repetition avoidance (e.g., Falk & Konold, 1997; Mittenecker, 1953; Wagenaar, 1970). When the number of response alternatives is sufficiently large, not only immediate repetitions tend to be avoided, but also lagged repetitions (e.g., Towse, 1998; Towse & McLachlan, 1999; Towse & Valentine, 1997). Application of the local-representativeness criterion requires a running memory of a number of preceding responses and the application of a rule according to which the most recent of the remembered responses are given less weight in selecting the next response.

Nonattentional response selection is based on the availability of the alternative responses. Differences in the unconditional availability of the responses give rise to different relative frequencies. Unconditional availability is affected by a number of factors. Of course, these factors vary across different types of response. For example, the relative frequencies of the various letters of the alphabet in a random letter generation task reflect their frequencies in natural language (Attneave, 1953; Moosbrugger, 1972). When responses are ordered on a conceptual continuum as in number generation or a physical continuum as in key-press generation, responses at the ends of the range tend to be less frequent than those in the middle (e.g., Heuer, Kohlisch, & Klein, 2005). Perhaps even more subtle are differences in the relative frequencies of leftward and rightward turns of a bimanually held handle, which depend on whether the head is rotated to the left or right (Heuer & Klein, 2001).

More important than the variations of unconditional availability are those of conditional availability, which reflect the associative or other relations among the response alternatives within a set. For example, in random letter generation there is a tendency to name letters in alphabetic order (e.g., van der Linden, Beerten, & Pesenti, 1998), and in random number generation there is a tendency to count upwards or downwards (e.g., Brugger, Milicevic, Regard, & Cook, 1993). For key-presses with the 10 fingers Baddeley et al. (1998) observed a bias toward next responses with the same finger of the other hand, which is likely to reflect a well-known constraint on bimanual coordination (cf. Heuer, 1996). Thus, with different response sets there are different patterns of conditional availability, which are most likely based on different types of relations among the various responses.

In random generation, attentional control embraces not only application of the local-representativeness criterion (or perhaps some other criterion for subjective randomness of a sequence), but also inhibition of nonattentional control or the results thereof—that is, inhibition of prepotent responses. Findings on individual differences are consistent with this notion. Principal component analyses of 15 or 16 dependent measures as described by Towse and Neil (1998) produced a four-factor solution for the data of Towse and Valentine (1997), whereas Miyake, Friedman, Emerson, Witzki, Howerter, and Wager (2000) found a three-factor solution. The latter solution differed from the four-factor solution primarily in that two of the four factors merged into a single factor on which measures of repetition tendencies at various lags loaded. The other two factors were labelled "equality of response usage", conceptually related to application of the local-representativeness criterion, and "prepotent associates", conceptually related to variations of response availability. A structural model revealed the relation of these factors to latent variables called "updating" and "inhibition", respectively. The tasks that contributed to the latent variable "updating" were variants of running-memory tasks, whereas the tasks contributing to the latent variable "inhibition" were an antisaccade task, a stop-signal task, and a Stroop task. These findings are highly consistent with the two-process model of random generation that is suggested by experimental research.

Both from a functional and from a structural perspective there are good reasons to expect that random generation is impaired at higher adult age. In fact, van der Linden et al. (1998) reported an impairment of random letter generation in this particular population. Older adults produced more stereotyped responses than younger adults—that is, more pairs of letters in alphabetical order. However, for other dependent variables, which reflect, for example, unequal frequencies of the responses or the frequency of immediate repetitions, there were no reliable differences between the two age groups. Only with respect to missed responses was performance of the older participants poorer, in particular with fast pacing. This latter finding probably reflects generalized cognitive slowing. When random letter generation was performed simultaneously with a card-sorting task, older participants also showed higher zero-order redundancy than did younger participants—that is, larger differences between the relative frequencies of the various responses. These findings can be taken to suggest that at higher age primarily the inhibition component of random generation is impaired, but not the updating function or other processes involved in implementing the application of the local-representativeness criterion.

The effects of factors such as age on random generation are likely to depend on the particular task variant used. This is to be expected in particular for the inhibition of prepotent responses, because the factors that affect response availability are specific to the particular response set. For example, Heuer et al. (2005) found that one night of total sleep deprivation impaired the inhibition of prepotent responses in a random number generation task and in a random noun generation task, but not in random key-press generation. In addition, for random key-presses with a small response set of only four alternatives the attentional process of response selection was impaired, which was not the case with larger response sets. From these findings one might expect that for ageing the results might be affected by the number of response alternatives, too. Thus to explore the generality of the findings on age-related changes of random letter generation reported by van der Linden et al. (1998) we used not only a different response set, spoken nouns, but also a smaller number of responses.

Random noun generation in a slightly different form than in the present study has been used by Heuer et al. (2005), but we are not aware of other studies. In the present study participants were first asked to learn a set of six nouns from two different categories and subsequently to produce these nouns in a random sequence. Nonattentional processes of response selection, which favour prepotent responses, should result in a within-category bias—that is, a tendency to produce nouns of the same semantic category as that used briefly before. To the extent that the inhibition of such prepotent responses is affected by age, the within-category bias should be stronger in the old than in the young participants.

Method

Participants

The random noun generation task was performed by 109 participants, 57 in the young group between 20 and 30 years of age (mean: 23.8 years, $SD = 2.5$ years), and 52 in the old group between 50 and 67 years (mean: 56.5 years, $SD = 4.7$ years). Among the young participants there were 22 men and 35 women, and among the old participants there were 29 men and 23 women.

Participants performed the random noun generation task in several different experiments on motor learning as a part of a set of tests on general intellectual and motor abilities. Among the intelligence tests were the Digit Symbol Test and the Vocabulary Test of the German version of the Wechsler Adult Intelligence Scale (WAIS). Whereas in the Digit Symbol test the young participants outperformed the old participants (61.7 vs. 49.3), $F(1, 105) = 37.1$, $p < .01$, there was no age-related difference in the Vocabulary test (24.8 vs. 24.4), $F < 1$. (The means given here for the young and old participants are means of the means of the male and female subgroups, so that the comparison between age groups is not confounded by the somewhat different gender proportions. In the analyses of variance, ANOVAs, as in all other ANOVAs reported in this paper, gender was included as a between-participant factor in addition to age. Therefore the age effects in these analyses cannot be attributed to possible differences between male and female participants and their different proportions in the two age groups. The few statistically significant effects of gender per se are not reported because they are not of interest for the purpose of the present study.)

Task and procedure

Participants were instructed to produce a random sequence of length 100 with six nouns as elements. The nouns were from two categories: musical instruments (flute, violin, piano) and insects (fly, mosquito, wasp). For each of these two categories they were among the four most frequent associates to the category name (Mannhaupt, 1983). The German words (Flöte, Geige, Klavier, and Fliege, Mücke, Wespe) were all two-syllable words with different vowels in the first syllable. Two words (Flöte and Fliege), one of each category, were chosen with the same initial consonants. However, the identity of the initial consonants did not enhance the corresponding transitions between categories; therefore this feature of the nouns is neglected in the presentation of the results. The meaning of "random sequence" was explained by means of referring to throwing a dice with a noun instead of a number on each side.

The task began with the presentation of the words on the monitor, one above the other in a random arrangement. Participants were instructed to learn the words until they felt ready for the task. After a training phase of 25 responses the nouns were shown again in a new random order, followed by a first sequence of 100 responses. A second sequence of 100 responses followed after the nouns had been shown again in another random order. Production of the nouns was visually paced by means of a circle on the monitor, which blinked with a rate of once per two seconds. Participants were instructed to omit a response if they had difficulties in following the pace.

Data analysis

The vocal responses of the participants were transcribed to the numbers 1 to 6; occasional intrusions were coded as 7. Intrusions as well as omissions were rare. Therefore the fact that they occurred was neglected in the sequential analyses, which were performed separately on each of the two sequences of each participant and collapsed. (Omissions amount to a local slowing of sequence generation. The neglect of intrusions can result in negligible errors in the sequential analyses in these rare instances. For example, a repetition lag would be treated as smaller than it really is. However, this represents an error only if intrusions share processes of response selection with regular responses and are not just a kind of filler for what would have been an omission otherwise.)

In addition to the mean number of correct responses and the mean number of omissions, the mean relative frequencies of the six nouns were computed. Variations of these frequencies were assessed as global unevenness, which is the root mean squared deviation from equal relative frequencies (multiplied by 100 and expressed as percentage). Local unevenness was assessed in the same manner, but for running windows of widths 6, 12, and 18 responses instead of whole sequences. The means of all windows of a participant were computed and entered in the statistical analyses.

To capture sequential dependencies, relative frequencies of response repetitions were computed for various lags. Similarly, relative frequencies of category repetitions were computed for several lags. Category repetitions were defined in two different ways for these computations, inclusive and exclusive of response repetitions. For example, relative to its first element the sequence flute–fly–flute–violin would be counted both as a lag-2 and a lag-3 category repetition including response repetitions, but only as a lag-3 category repetition excluding response repetitions. Related to the relative frequencies of category repetitions are the relative frequencies of within-category runs of different lengths. For example, the sequence flute–fly–flute–violin consists of two runs of length 1 and one run of length 2.

Results

The results are presented for the various dependent variables in sequence.

Number of responses and intrusions

The number of correct responses actually produced in each sequence was slightly less than 100 because of omissions and intrusions. For the young participants there were 98.7 and 98.9 responses on average in the first and second sequence, respectively, whereas for the old participants there were 96.5 and 98.5 responses. An ANOVA with the between-participant factors age and gender and the within-participant factor sequence (first vs. second) revealed only a significant main effect of sequence (97.4 vs. 98.7), $F(1, 105) = 8.2$, $p < .01$. The young participants produced slightly more responses than the old participants (98.5 vs. 97.5), but this difference lacked statistical significance, $F(1, 105) = 2.5$, $p > .10$. The total number of intrusions was 0.3 and 0.7 for young and old participants, respectively. Again this difference was not statistically significant, $F(1, 105) = 1.9$, $p > .10$.

Relative frequencies of nouns and global unevenness

The relative frequencies of the six nouns are shown in Figure 1, with the three nouns of each category being arranged in order of increasing relative frequency (as is evident from the figure). In the two age groups there were systematic deviations from the expected relative frequencies of .167. Musical

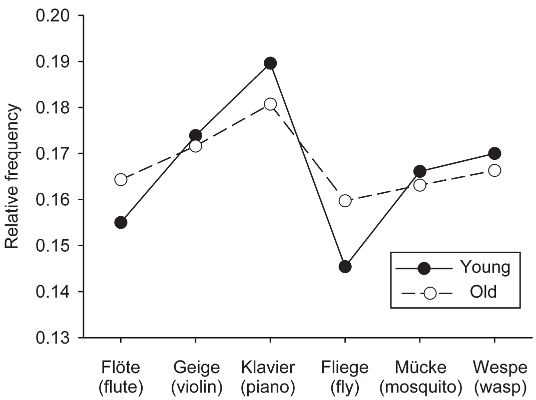

Figure 1. *Mean relative frequencies of the nouns in the young and old participants.*

instruments were named somewhat more frequently than insects (.173 vs. .161), and within each category the variation across nouns was somewhat stronger for young participants than for old ones. An ANOVA with the between-participant factors age and gender and the within-participant factors category and word-within-category revealed a significant main effect of category, $F(1, 105) = 30.3$, $p < .01$, as well as a significant main effect of word-within-category, $F(2, 210) = 38.5$, $p < .01$, and a significant interaction of word-within-category with age, $F(2, 210) = 4.9$, $p < .01$.

In addition to the consistent variations of relative noun frequencies shown in Figure 1 there are variations which are inconsistent across participants. Both these kinds of variation of relative frequencies across nouns were assessed as global unevenness, the root mean squared deviation of the observed relative frequencies from the expected ones computed for each participant and expressed as percentages. Global unevenness was 2.6% for the young participants and 2.0% for the old participants. An ANOVA with the between-participant factors age and gender revealed a significant main effect of age, $F(1, 105) = 5.6$, $p < .05$. To obtain a baseline measure of global unevenness in random sequences of 98 elements, which was about the average number of responses produced by the participants, we generated 10,000 pairs of random sequences of length 98. Their mean global unevenness was 2.5%. Thus the global unevenness of young adults matched that of random sequences, whereas the global unevenness of old participants was smaller.

Local unevenness

Local unevenness was determined for running-window widths of 6, 12, and 18 responses. With the simulated random sequences (see above) the measures of local unevenness were 14.6, 10.3, and 8.4%. The observed measures of local unevenness were 9.7, 6.6, and 5.5% for the young participants, and 8.1, 5.5, and 4.5% for the old participants. Thus, the local unevenness of the sequences produced by the participants was smaller than that of random sequences, and it was smaller for the old participants than for the young participants, in particular at the narrow windows. An ANOVA with the between-participant factors age and gender and the within-participant factor window width revealed significant main effects of age, $F(1, 105) = 14.2$, $p < .01$, and window width, $F(2, 210) = 1{,}216.0$, $p < .01$, and a significant interaction of age and window width, $F(2, 210) = 8.6$, $p < .01$.

In Figure 2a the cumulative distributions of local unevenness are shown for a running-window width of 6 responses, both for the young and for the old participants and for the simulated random sequences. The variability among the participants was larger than that among the simulated random sequences. The important point of Figure 2a, however, is that the distributions of old and young participants differed both for small and for large measures of unevenness. Thus the difference in the means was not due just to an abundance of old participants with local unevenness close to zero. Local unevenness of zero implies that in each running window of width 6 each of the 6 responses occurs once, and this again implies that the same permutation of the 6 responses is repeated over and over again. Figure 2b illustrates such a fictitious sequence of 16 responses and its 11 running windows. Local unevenness of 0% was observed in no participants; the observed minimum was 2.6%.

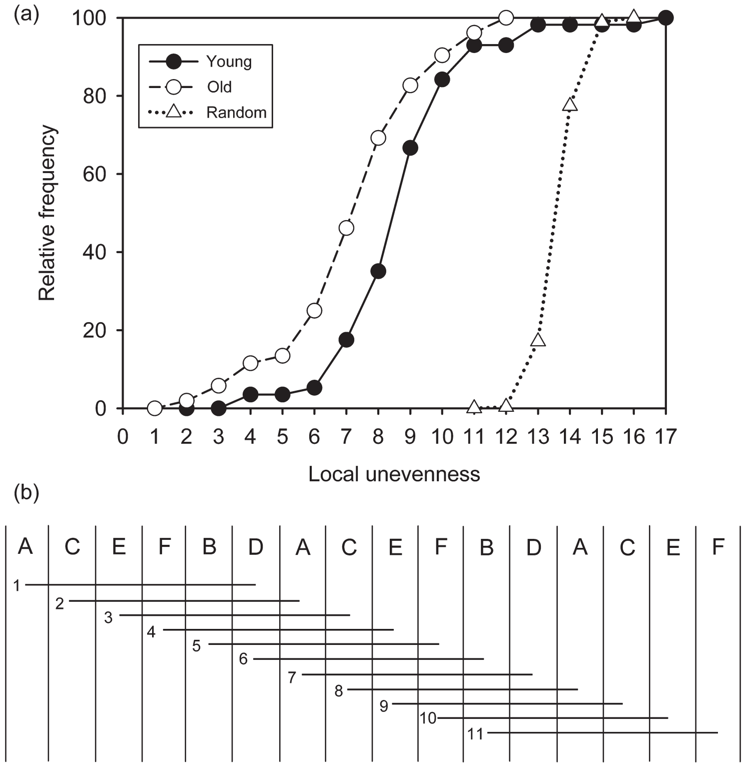

Figure 2. *(a) Cumulative relative frequencies (as percentages) of local unevenness (window width of 6 responses) for young and old participants and for sequences generated by a random process. (b) Fictitious sequence with a repeated permutation of the elements {A, B, C, D, E, F} and running windows of width of 6 responses in which each element occurs once so that local unevenness is zero.*

Word repetitions

The relative frequencies of word repetitions as a function of lag are shown in Figure 3 both for young and old participants. For random sequences these should be about .167 throughout, independent of lag. At short lags the observed frequencies were much smaller, consistent with the generally found repetition avoidance. At longer lags the observed frequencies became larger than those of random sequences, and at even longer lags they exhibited a periodicity. There was a tendency to repeat words after five other words had intervened. In old participants the repetition avoidance at short lags was more pronounced than in young participants, and so was the periodicity at longer lags. An ANOVA with the between-participant factors age and gender and the within-participant

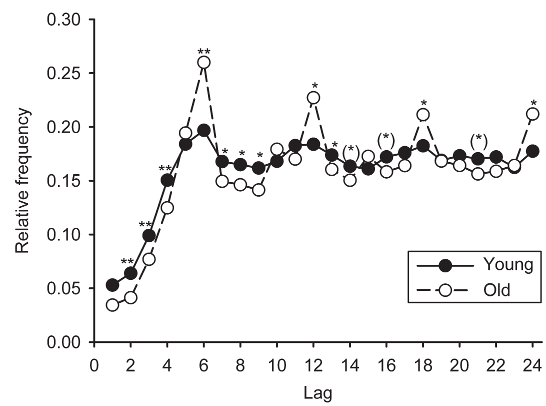

Figure 3. *Mean relative frequencies of word repetitions at lags 1 (immediate repetitions) to 23 in young and old participants. Significant age contrasts are marked by asterisks: $^{**}p < .01$; $^{*}p < .05$; $^{(*)}p < .10$.*

factor lag revealed a significant main effect of lag, $F(23, 2415) = 54.2$, $p < .01$, and a significant interaction of lag with age, $F(23, 2415) = 4.0$, $p < .01$. (In Figure 3 significant differences between the age groups at each lag are marked by asterisks.)

Category repetitions

The relative frequencies of category repetitions are shown in Figure 4a. At longer lags, beginning at lag 3 or 4, these data look quite similar to the relative frequencies of word repetitions. The main difference was that the overall average at longer lags was close to .50 rather than .167. Category repetitions include word repetitions, and the pronounced variation of the relative frequencies of word repetitions across lags seems to determine the pattern of relative frequencies of category repetitions. Therefore relative frequencies of category repetitions were also determined excluding word repetitions. These are relative frequencies of the two words of a category not produced as a response in a certain serial position. The relative frequencies of word-exclusive category repetitions are shown in Figure 4b.

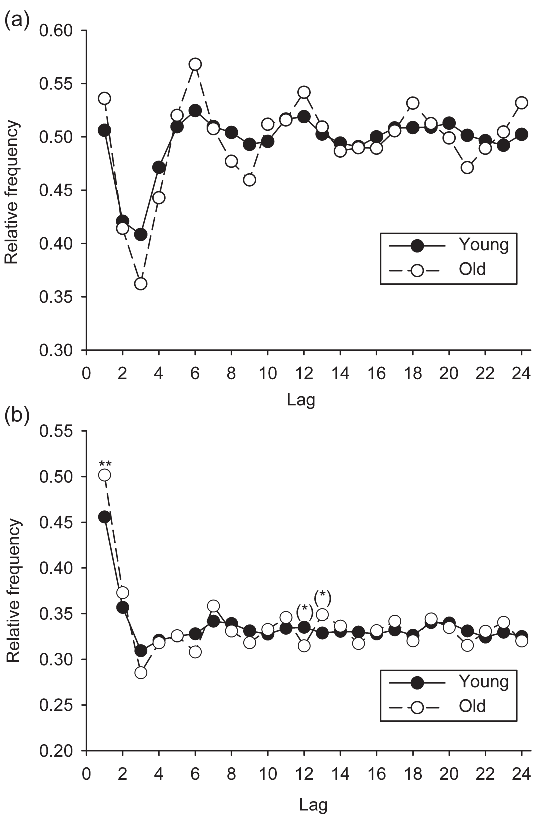

Figure 4. *Mean relative frequencies of category repetitions at lags 1 (immediate repetition) to 23 in young and old participants. In (a) word repetitions are included, in (b) they are excluded. Significant age contrasts are marked by asterisks in (b).*

From Figure 4b it is apparent that word-exclusive category repetitions at lag 1 were more frequent than those expected for random sequences, still slightly more frequent at lag 2, and slightly less frequent at lag 3. At longer lags the observed relative frequencies settled down close to the expected relative frequency for random sequences of about .333. For older adults category repetitions were more frequent at lag 1, but at all other lags contrasts revealed no reliable age variation. Except perhaps for the age-related differences at lags 2 and 3, at the longer lags the differences appeared rather haphazard. An ANOVA with the between-participant factors age and gender and the within-participant factor lag revealed a significant main effect of lag, $F(23, 2415) = 33.8$, $p < .01$, and a significant interaction of lag with age, $F(23, 2415) = 1.9$, $p < .01$.

Within-category runs

The relative frequencies of within-category runs of lengths 1 to 6 are shown in Figure 5. The expected frequencies for random sequences are about .5, .25, .125, .063, .031, and .016. For lengths 1 and 3 there were the most obvious deviations between observed data and random-based expectations, and these deviations were more pronounced for old than for young participants. An ANOVA with the between-participant factors age and gender and the within-participant factor run length revealed a significant main effect of run length, $F(5, 525) = 230.8$, $p < .01$, and a significant interaction of run length with age, $F(5, 525) = 4.9$, $p < .01$. Contrasts of the two age groups for each run length revealed significant age-related differences for run lengths 1 and 3.

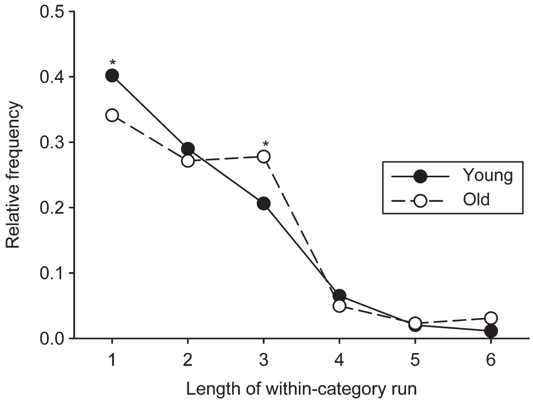

Figure 5. *Mean relative frequencies of within-category runs of lengths 1 to 6 in young and old participants. Significant age constrasts are marked by asterisks.*

Discussion

The present data reveal some fundamental characteristics of human random generation also for random noun generation, even though the availability of responses is governed by factors other than those in the more common tasks of random number generation, random letter generation, or random key-press generation. In addition, random noun generation exhibited age-related variations. We discuss both the characteristic deviations from randomness and the age-related variations in turn.

The most conspicuous and consistent characteristic of human-generated random sequences is repetition avoidance (e.g., Mittenecker, 1953; Wagenaar, 1970). This was clearly present, and it stretched over more than just a single serial position as is typical for sufficiently large response sets (cf. Towse, 1998; Towse & McLachlan, 1999; Towse & Valentine, 1997). A direct measure of local unevenness (cf. Heuer et al., 2005; Spatt & Goldenberg, 1993), which is not commonly used, gave more direct evidence of the application of a local-representativeness criterion in that random sequences exhibit a considerably stronger local unevenness than do human-generated sequences.

In some experiments response sets are chosen to avoid variations of unconditional and conditional response availability and, as a consequence, prepotent responses (e.g., Mittenecker, 1958, 1960). However, prepotent responses or their inhibition can be of high interest when the purpose is not to study human skills in dealing with randomness (cf. Nickerson, 2002), but to exploit random generation tasks for the assessment of the cognitive consequences of brain lesions (cf. Brugger, 1997) or of functional variations of the brain as induced by hormonal variations (Brugger et al., 1993), by sleep deprivation (Heuer et al., 2005), or by ageing. Prepotent responses are of different types, depending on the response set. For random noun generation they are same-category responses (cf. Heuer et al., 2005), and these were pronounced in the present experiment. First, category repetitions at lag 1 (i.e., immediate repetitions) were more frequent than in random sequences; second, within-category runs of length 1 were less frequent, and those of length 3 were more frequent, than in random sequences.

Turning to age-related variations of random noun generation, these were basically of two kinds. First, the tendency to produce category repetitions becomes stronger at older age. This finding is consistent with the observation of van der Linden et al. (1998) of a stronger stereotyping in random letter generation. The reduced inhibition of prepotent responses is also in line with the notion of generalized impairment of inhibitory processes with increasing age (cf. Gazzaley, Cooney, Rissman, & D'Esposito, 2005; Hasher, Stoltzfus, Zacks, & Rypma, 1991; Hasher & Zacks, 1988). However, the notion of inhibition covers a broad range of phenomena and brain regions, and it is unlikely that there is no differentiation with respect to age-related variations (e.g., Kramer, Humphrey, Larish, Logan, & Strayer, 1994). Thus, even though reduced inhibition of prepotent responses with increasing age has been observed both for the random letter and for the random noun generation tasks, it could be absent for other response sets for which availability is determined by factors that are not related to working-memory functions. For example, after a night without sleep prepotent responses become more pronounced in random number generation and random noun generation, but not in random key-press generation (Heuer et al., 2005). Such behavioural effects of sleep deprivation are attributed to its effects on the functions of the frontal lobes, which are also ascribed a critical role in cognitive ageing. Therefore, age-related variations with respect to the inhibition of prepotent responses might not generalize to all sorts of response sets as well.

In the present study we observed a second kind of age-related effect which was absent in the data of van der Linden et al. (1998). Older participants exhibited stronger repetition avoidance. In addition the local unevenness of their sequences was weaker than the local unevenness of the sequences of young participants. Both these observations point to a stricter application of a local-representativeness criterion. Thus, older participants had a stronger tendency not only to produce the nouns category-wise, but also to cycle through the whole set of nouns before repeating one. Therefore the relative frequencies of word repetitions exhibited a periodicity in particular for the old participants. However, the stronger tendency of older participants to cycle through the whole set of responses before repeating one did not take the extreme form of repeating a single permutation of the nouns over and over again. It was also not due to just a few older participants who approximated such a systematic strategy to achieve local representativeness.

The discrepancy between the findings of van der Linden et al. (1998) and the present findings with respect to repetition avoidance is likely due to the different numbers of response alternatives. Consider a window of running memory within which the local-representativeness criterion is applied. With a small set of responses each response should occur at least once in the window, and a response repetition should be produced only with a certain lag. This requires a representation of the serial order of the preceding responses. In contrast, with a large set of responses it is sufficient to select a response that was not in the window of running memory. A representation of serial order is not required for this. Thus, in terms of its implementation the local-representativeness criterion might differ depending on the size of the response set. In line with such considerations, Heuer et al. (2005) found an effect of sleep deprivation on local unevenness (and, though nonsignificant, on repetition avoidance) only with four, but not with eight, alternative responses in a random key-press task. However, this effect was opposite to the one found here for ageing, and it was absent in the six-alternative random noun generation task. Thus, although the number of response alternatives can modulate the effect of sleep deprivation and perhaps of ageing, these modulations should be different.

Alternatively the discrepancy between the present findings and those of van der Linden et al. (1998) could be due to the different age ranges studied. The older participants were between 60 and 70 years (mean: 66.1 years) in the study of van der Linden et al., but only between 50 and 67 years (mean: 56.5 years) in the present study. Such an account would be supported by appropriate trends among the younger older participants. If their repetition probability would increase with increasing age from 50 to 67 and, similarly, local unevenness, one would expect higher values for the older old participants between 60 and 70, which could be no longer different from those observed for young adults. Stricter application of a local-representativeness criterion would then be a transient phenomenon limited to higher working age. However, the respective correlations with age for the 52 old participants failed to reach statistical significance. For the relative frequencies of noun repetitions at lags 1 to 6 they were −.15, .12, −.09, −.11, .12, and .13, respectively; for the measures of local unevenness for window widths of 6, 12, and 16 responses they were −.10, .03, and .04, respectively. Thus, the present data reveal no trend that would allow one to infer different findings for a somewhat older group of participants, conforming to those reported by van der Linden et al. (1998).

In terms of the two modes of response selection, the nonattentional and the attentional mode, which roughly correspond to the contention scheduling and the supervisory attentional system of Norman and Shallice (1980, 1986), the data suggest that the attentional mode becomes more pronounced in older adults, whereas the results of the nonattentional mode become less inhibited (or the nonattentional mode becomes more pronounced as well). Whether or not the stronger attentional control of response selection is a strategy to overcome age-related deficits, driven perhaps by appropriate metacognitive knowledge, is an interesting question for the future. Another question is which signatures of stronger attentional control of response selection and stronger nonattentional control (or weaker inhibition thereof) can be identified in other types of task. For example, in some tasks like counterupdating or task switching (Janczyk, Wienrich, & Kunde, 2008) an equivalent of stronger repetition avoidance could be a reduced expectancy of full repetitions. Similarly, an equivalent of stronger within-category bias could be a stronger expectancy of category or task repetitions.

A core feature of cognitive ageing is generalized slowing, which can be observed in a manifold of tasks (e.g., Li, Lindenberger, & Sikström, 2001b; Myerson, Hale, Wagstaff, Poon, & Smith, 1990; Welford, 1981). It is always possible that age-related variations in some kinds of task are just a consequence of slower cognitive processing (cf. Salthouse, 1996; Salthouse & Babcock, 1991; Salthouse & Meinz, 1995). Of course, cognitive slowing can also affect random generation (cf. Fisk & Warr, 1996). However, in the present task there was no reliable evidence of stronger time pressure for the old than for the young participants, although omissions and intrusions were slightly, but nonsignificantly, more frequent.

Cognitive slowing together with a certain pacing rate should produce qualitatively the same effects on random generation as a faster pacing rate without cognitive slowing. Thus, differences in random generation that result from slower cognitive processing should be of the same kind as differences that show up when the pacing rate is increased. In a previous study, Heuer et al. (2005) used two different pacing rates for each type of random-generation task, including random-noun generation. A faster pacing (1 s instead of 2 s) resulted in a stronger same-category bias. This effect of faster pacing is typical for most random-generation tasks. It is plausible because lack of time should result in a stronger weight of (faster) nonattentional response selection and a smaller weight of (slower) attentional selection. However, in none of the tasks studied did a faster pacing result in a stronger repetition avoidance (or smaller local unevenness); in contrast, with a faster pacing repetition avoidance tended to be weaker, though the differences were not statistically significant. The decline of repetition avoidance at faster rates again is plausible because repetition avoidance is hypothesized to result from the (slow) attentional process and its use of the local-representativeness criterion or some other criterion for subjective randomness.

From these observations and considerations it is evident that cognitive slowing can perhaps account for the stronger same-category bias of the older participants, but not for their stronger repetition avoidance and smaller local unevenness. Thus, cognitive slowing cannot account for the full set of the present data, and there remain doubts that it offers a valid account even for a part of the data (cf. van der Linden et al., 1998).

In terms of randomness of the sequences produced, both stronger response bias and stronger repetition avoidance represent poorer performance of the older participants. However, the stricter application of the subjective concept of randomness by the older participants can also be viewed as better performance in terms of the attentional control of behaviour. Stronger attentional control might be a more general characteristic of ageing, which underlies diverse phenomena like enhanced accuracy in reaction-time tasks (e.g., Salthouse, 1979) or poorer dual-task performance with combinations of seemingly simple motor tasks such as walking and cognitive tasks (Li, Lindenberger, Freund, & Baltes, 2001a; Lindenberger, Marsiske, & Baltes, 2000; Riby, Perfect, & Stollery, 2004). Consistent with such a functional view are brain-imaging results. Both for simple cognitive tasks and for motor tasks increasing age is associated with wider brain activation, in particular less lateralized activity and additional activity of prefrontal areas (cf. Heuninckx, Wenderoth, Debaere, Peters, & Swinnen, 2005; Reuter-Lorenz, 2002).

Random sequences of older participants were more affected than those of younger participants by conditional response availability as reflected in the same-category bias, but they were less affected by unconditional response availability. The differences between the relative frequencies of the various response alternatives were smaller for them, and global unevenness was smaller as well. Such an age-related difference has been absent in the study of van der Linden et al. (1998). Most likely the smaller variation of the relative frequencies of the response alternatives found for the older participants in the present study is related to their stricter application of the local-representativeness criterion, which serves to reduce not only local unevenness, but also global unevenness.

The origin of the overall differences between the relative frequencies of the response alternatives is unclear: Musical instruments were named somewhat more frequently than insects, and within each category there were again systematic differences that corresponded neither to the strength of the association to the category name (cf. Mannhaupt, 1983) nor to the word frequency in German according to the "Digitales Wörterbuch der deutschen Sprache des 20. Jh" of the *Berlin-Brandenburgische Akademie der Wissenschaften* (2008). Whereas the ranking of Flöte (flute), Geige (violin), and Klavier (piano) was consistent with word frequency, the ranking of Fliege (fly), Mücke (mosquito), and Wespe (wasp) was just the opposite. Perhaps the unconditional availability of the insect names was related to the harm they can do to humans, with the wasp ranking first and the fly ranking last.

Summing up, the present data confirm the age-related impairment of inhibition of prepotent responses in a random noun generation task. In addition, they reveal a stricter attentional (or strategic) control of response selection in the older participants. Both these age-related changes are not limited to random generation, but have known or hypothetical, but not yet confirmed, equivalents in other types of task.

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