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Cognitive estimation in patients with probable Alzheimer's disease and alcoholic Korsakoff patients

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Abstract

Cognitive estimation is an important function in daily living. In early studies it was proposed that estimation deficits are associated with frontal lobe damage and executive dysfunctions. In this study, we assessed Alzheimer patients and patients with alcoholic Korsakoff's syndrome with a newly developed cognitive estimation task. We compared their performance with respect to different dimensions of estimation ('size', 'weight', 'quantity', and 'time') and to various error types. Compared to healthy controls, both patient groups were strongly impaired in all tested estimation dimensions, with Alzheimer patients performing generally worse than Korsakoff patients, except for the dimension "time". Alzheimer as well as Korsakoff patients produced so-called 'bizarre errors' and errors in the choice of the correct unit of measurement. In both patient groups cognitive estimation correlated highly with general knowledge. The production of bizarre errors and unit errors correlated with general knowledge as well as with working memory and executive functions. Results support the main assumptions of a model of cognitive estimation, described in the discussion, that specific parts of the semantic memory system as well as executive functions, in form of a plausibility check of the generated answer, are involved in the process of cognitive estimation.

Keywords: Alzheimer's disease; Korsakoff's syndrome; Executive functions; Semantic memory

1. Introduction

Many activities in daily life depend on guesses and estimates. For example, if we are asked how many people were at the party last night or the weight of our carry-on luggage, we may guess if we do not know the exact answer, and usually we are satisfied by our estimates.

Cognitive estimation can be defined as a process of generating an answer while the exact solution is not readily available. In this process semantic information and (comparison) strategies are used to generate an appropriate answer [4].

Although cognitive estimation is an important neuropsychological function there are only a few studies concentrating on this topic. Possible underlying neuropsychological and behavioural mechanisms of cognitive estimation and the kind of brain damage leading to estimation disturbances still are largely unclear. Shallice and Evans [42] developed the Cognitive Estimation Test (CET) and found that patients with frontal lobe lesions showed deficits in this task. The importance of the frontal lobes in cognitive estimation was also described by Smith and Milner [46,47]. Some studies found deficits in cognitive estimation in Alzheimer's disease [4,14,22,50], in alcoholic Korsakoff's syndrome [22,23], and in traumatic head injury patients [12]. Mendez et al. [27] presumed that the CET may discriminate frontotemporal dementia from Alzheimer's disease and demonstrated that Alzheimer patients produced more absurd estimates than patients with frontotemporal dementia. They argued that the more pronounced semantic memory deficits in Alzheimer patients result in stronger estimation impairments characterised by absurd answers, although this result is somewhat astonishing because of the typically more pronounced frontal lobe damage and associated executive dysfunctions in patients with frontotemporal dementia.

However, the relationship between cognitive estimation and the different neuropsychological domains that impact it, is not consistently described across different studies. The presumed correlation between performance in the CET and

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so-called 'frontal' or executive functions, for example performance in the Wisconsin Card Sorting Test [31] could not be verified (e.g. [22,45]). Nevertheless Shoqueirat et al. [45] found a correlation approaching significance between the CET and a verbal fluency task which was regarded as a measure of executive functions (see [7]). A more recent study with schizophrenic and depressive patients [5] corroborated the covariance of cognitive estimation and executive functions which were assessed by a verbal fluency task.

Several memory components may also be involved in cognitive estimation. Freeman et al. [12] described a correlation between CET performance and subtests of the Wechsler Memory Scale (WMS-R) [55] (logical memory and visual reproduction) in patients with traumatic brain injury. A comparable result was not obtained by Brand et al. [5] in schizophrenic and depressive patients, although a correlation between cognitive estimation and the subtest information (as a measure of semantic memory) of the Wechsler Adult Intelligence Scale Revised (WAIS-R) [54] was found. Arithmetical abilities as well as intelligence seem to be unrelated to performance of cognitive estimation [12,14,22,46]. Until now, no study has examined different dimensions of cognitive estimation (e.g. 'size' or 'time') and compared the specific disturbances of one or more estimation dimensions in brain damaged patients. In addition, comparisons of performance on specific dimensions between different patient groups have not been examined (e.g. some dimensions appear to be only disturbed or more difficult for Alzheimer patients).

Most of the above mentioned studies administered a version of the CET which consists of 15 questions assessing different aspects of estimation (e.g. quantity of TV programmes on any TV channel between 6.00 and 11.00 pm; the width of a double-decker bus). However, Shallice and Evans [42] did not define specific dimensions (e.g. 'quantity' or 'size') but stated the questions on a one factor scale. Furthermore in the CET there are two different types of estimation tasks, those requiring numerical answers (e.g. the age of the oldest person in Britain today) and those requesting non-numerical responses (e.g. the largest fish in the world). The structure of the CET was criticised by O'Carroll et al. [32] who administered the test to a large sample of healthy controls and revealed in a component analysis that the CET does not measure a single factor. Additionally, the internal reliability of the CET seems to be unacceptable. For these reasons we developed a new test for cognitive estimation (German: *Test zum kognitiven Schätzen, TKS*) [3] consisting of 16 questions requiring numerical responses exclusively. The questions address the four dimensions 'size', 'weight', 'quantity' and 'time' (see description of the TKS below).

In this study, we assessed the performance of cognitive estimation in patients with Alzheimer's disease (AD), Korsakoff's syndrome (KS) and healthy controls (CG) using the TKS. AD patients are known to exhibit several memory impairments including learning new information and recall of information from the semantic memory system as well as other cognitive disturbances, such as aphasia, agnosia or executive dysfunction (see [40] for a review). Due to their multifaceted cognitive deteriorations AD patients are expected to be strongly impaired in all dimensions of cognitive estimation. KS patients may exhibit profound anterograde amnesia with varying degrees of retrograde memory impairments [23,25] in the absence of global intellectual decline. Furthermore, confabulations and disturbances in the sense of time can occur (see ICD-10 [56] and DSM-IV [1]). KS patients also show deficits in so-called 'frontal' or executive functions [18,22]. Therefore it is expected that they will be impaired in all dimensions of cognitive estimation when compared to controls. Moreover, time estimations should be most severely affected considering their disturbed sense of time. Due to the generally more pronounced cognitive impairments of AD patients it is presumed that they will show greater deteriorations in cognitive estimation than those with KS.

2. Participants and methods

2.1. Statistical analyses

All statistical analyses were carried out with the Statistical Package for the Social Sciences (SPSS) version 10.0 for Windows (Release 10.0.7 (1 June 2000) Chicago: SPSS Inc.). In case of normally distributed data we used parametric methods (*t*-tests, univariate analyses of variance, analyses of variance with repeated measurements and Pearson correlations), and in case of significant deviations from the normal distribution (tested with the Kolmogorov–Smirnov-test) we used corresponding non-parametric methods (χ^2-test, Mann–Whitney *U*-tests, Kruskal–Wallis *H*-test and Spearman correlations). To adjust for multiple comparisons, results were corrected (Bonferoni).

2.2. Participants

A total of 50 patients with probable AD according to NINCDS–ADRDA criteria [26] exhibiting mild to moderate dementia, 50 patients with clinically diagnosed alcoholic KS according to ICD-10 [56] and DSM-IV [1] criteria (for alcohol-induced amnesic syndrome or alcohol-induced persisting amnestic disorder, respectively), and 50 healthy controls were enrolled in the study. The AD patients were recruited from the Clinic of Neurology of the University of Cologne, Germany, and the KS patients from different homes for chronically-multi-impaired addicts of the Allgemeine Hospitalgesellschaft (AHG), Germany. All patients underwent an extensive neurological and psychiatric examination, done by the physicians of the different cooperating institutions. The history of alcohol consumption of the KS patients was revealed by checking medical documentations and by interviewing their relatives. All KS patients had extensive alcohol consumption over continuous periods of

Table 1
Socio-demographic description of the three groups

	AD ($n = 50$)	KS ($n = 50$)	CG ($n = 50$)
Age in years			
Mean (S.D.)[a]	67.5 (9.5)	56.3 (6.6)	64.8 (8.4)
Gender			
Male	25	32	19
Female	25	18	31
Education			
9 years	34	38	21
10 years	7	6	16
12 years	9	6	13
MMSE			
Mean (S.D.)[a]	20.5 (4.0)	24.5 (2.2)	NA[b]
CDR			
Median (range)	2 (0.5–3)	0.5 (0–2)	0

[a] S.D.: standard deviation.
[b] NA: not administered.

more than 12 years. They did not, however, exhibit typical signs of dementia and were therefore not diagnosed as patients with alcohol related dementia according to the criteria of Oslin et al. [34]. For both patient groups, subjects with further (current or history of) neurological or psychiatric symptoms were excluded. Mean age, gender and education of the three groups are shown in Table 1.

The KS group was significantly younger than the AD patients ($P < 0.001$) and the CG ($P < 0.001$) while the AD patients and the CG did not differ ($P = 0.26$). Regarding gender and education the AD and KS patients were comparable ($P = 0.15$ and 0.63), while the CG had significantly more female subjects than the KS group ($P < 0.01$). The AD patients and the CG were comparable regarding gender ($P = 0.22$), but the CG was slightly higher educated than the AD and the KS patients.

2.3. Methods

2.3.1. Neuropsychological test battery

An extensive neuropsychological test battery was administered to the subjects (see Table 2 and Section 3.1 for the specific tests).The following cognitive domains were examined: intelligence, general knowledge, attention, verbal and figural short and long-term memory, executive functions, visuo-constructive abilities, and language comprehension. The general cognitive state was determined by a German version [20] of the Mini Mental State Examination (MMSE) [11] and the Clinical Dementia Rating Scale (CDR) [17].

2.3.2. Cognitive estimation

Cognitive estimation was assessed using the test for cognitive estimation (German: *Test zum kognitiven Schätzen, TKS*) [3]. The TKS includes the four dimensions 'size', 'weight', 'quantity' and 'time' and consists of 16 items (each dimension having four items). In the dimensions 'size', 'weight' and 'quantity' the patients are shown photos of different objects (see Fig. 1). For the dimension 'time' the patients are asked to estimate the duration of specific events (e.g. 'How long is the duration of a morning shower?').

The range of 'right' answers was established using the mean and *one* standard deviation of the solutions of the norm group (see [3]). For example, the range of right answers for the item 'fly' (see Fig. 1) is defined as between 0.8 and 2.4 cm. All answers outside of this range are scored as errors. For right answers (including one of the right units, e.g. centimetre or millimetre for the item 'fly') the subject obtains one point. The maximum total score of the TKS is 16.

3. Results

3.1. Neuropsychological test battery

The results in the neuropsychological test battery are shown in Table 2. The AD patients were more impaired in both the cognitive screening (Mini Mental State Examination, MMSE) [11] ($P < 0.001$) and the Clinical Dementia Rating Scale (CDR) [17] than the KS patients. Compared to the CG both patient groups were significantly (both P's < 0.001) impaired in a verbal selective reminding task (Memo-test [41]) in the immediate and the delayed condition, in a verbal fluency task (FAS-test

Fig. 1. Example of a TKS item of the dimension size (reproduced from [3] with permission).

Table 2
Results in the neuropsychological test battery

	Max	AD		KS		CG	
		Mean	S.D.[a]	Mean	S.D.[a]	Mean	S.D.[a]
MMSE	30	20.5	4.0	24.5	2.2	≥27[b]	
CDR	3	2[c]	0.5–3[d]	0.5[c]	0–2[d]	0	
Memo							
Immediate recall	10	4.0[c]	0.2–6.0[d]	5.0[c]	1.6–7.6[d]	7.6[c]	5.6–9.4[d]
Delayed recall	10	0[c]	0–4[d]	1[c]	0–6[d]	7[c]	3–10[d]
Digit span							
Forward	9	4.7	1.3	5.4	0.9	≥6[b]	
Reverse	9	2.8	1.0	3.6	1.0	≥4[b]	
Corsi's block span	8	3.3	1.6	4.5	0.9	≥5[b]	
CERAD							
Visuo-constructive	4	3[c]	0–4[d]	NA	NA	≥3[b]	
Rey–Osterrieth–Figure							
Copy	36	NA	NA	28[c]	8–36[d]	33.1[b]	
Delayed recall	36			2[c]	0–10[d]	16.6[b]	
FAS-test							
Total		16.1	8.9	22.9	10.2	39.4	10.2
AAT							
Auditory	30	21.4	5.0	NA	NA	≥ 28[b]	
Reading comprehension	30	23.4	4.1			≥28[b]	
FWT							
Words	S	20[c]	14–50[d]	16[c]	11–37[d]	≤16[b]	
Colours	S	39[c]	23–78[d]	28[c]	14–69[d]	≤22[b]	
Interference	S	116[c]	50–360[d]	53[c]	16–180[d]	≤41[b]	
Interference-colours	S	72[c]	21–321[d]	28[c]	9–120[d]	≤16[b]	
WCST							
Correct	48	NA	NA	28.1	7.8	NA	NA
Errors				13.8	5.9		
Perseverations				5.6	4.0		
LPS (reasoning)							
Correct	40	NA	NA	17.6	5.5	24.7	5.1
Estimated IQ				95.0	10.8	108.9	11.8
HAWIE-R							
Information	24	6.7	4.4	10.3	5.2	17.7	3.8

NA: not administered.
[a] S.D.: standard deviation.
[b] Scores of norm group.
[c] Median.
[d] Range.

[48]) (both P's < 0.001) and in the general knowledge (subtest information of the German version (HAWIE-R) of the Wechsler Adult Intelligence Scale—Revised [52]) (both P's < 0.001). The differences between the AD and the KS patients in these tests were also significant (P's from <0.001 to 0.003), except for the delayed condition of the Memo-test ($P = 0.054$). In comparison with a norm group, both groups were impaired in the digit span (subtest of the German version (HAWIE-R) of the Wechsler Adult Intelligence Scale—Revised [52]), the visuo-spatial memory (subtest Corsi's block span of the Wechsler Memory Scale—Revised [55]), the visuo-constructive abilities (copy of the Rey–Osterrieth–Figure [35] and subtest construction of the CERAD [29]), the speed of non-verbal information processing and the word colour interference test (subtest Word-Colour-test of the Nürnberger–Alters–Inventar [36]). The AD patients were slightly impaired in auditory and reading comprehension (subtest 2 and 4 of language comprehension of the Aachener Aphasie-test (AAT) [16]) and the KS patients had significantly lower reasoning abilities (subtest reasoning of the Leistungsprüfsystem [49]) compared to the controls ($P < 0.001$), although their estimated IQ was in the normal range of 100 ± 15. Compared to the KS patients the AD group was significantly impaired in the digit span ($P = 0.004$) and visuo-spatial memory (Corsi's block span) ($P < 0.001$), the speed of verbal and non-verbal

information processing (word trial and colour trial of the Word-Colour-test of the NAI) (both P's < 0.001), the interference (interference trial of the Word-Colour-test of the NAI) ($P < 0.001$) and the general knowledge (subtest information of the HAWIE-R) ($P < 0.001$).

In summary, the AD patients exhibited mild to moderate dementia and were more impaired in nearly all tested cognitive domains when compared with the KS patients. KS patients showed cognitive disturbances, such as executive dysfunctions in addition to the memory deficits typically observed.

3.2. Cognitive estimation

Both AD and KS patients scored lower in the TKS than the CG: AD: mean = 7.0, S.D. = 2.6; KS: mean = 9.1, S.D. = 2.7, and CG: mean = 12.9, S.D. = 1.3 (total score maximum = 16). In an analysis of variance there was a main effect for group ($F = 27.0$, $P < 0.001$) and no effect for age, gender and education. In separate analyses for the three groups no effect for age, gender and education was detected either. Therefore, performance in cognitive estimation seemed to be independent of these socio-economic factors and the between-group differences, reported in Section 2.2, could be neglected.

Both patient groups showed significant disturbances in the TKS (total score) compared to the CG (Scheffé: AD–CG: mean difference = −5.9, $P < 0.001$; KS–CG: mean difference = −3.7, $P < 0.001$) with AD patients were more impaired than KS patients (Scheffé: mean difference = −2.1, $P < 0.001$). The performance in the different dimensions of the TKS is shown in Fig. 2. In an analysis of variance with repeated measures there was a main effect for dimension ($F = 12.4$, $P < 0.001$) and a significant interaction of dimension and group ($F = 4.8$, $P < 0.001$). For both patient groups the dimension 'quantity' was the easiest. While for the AD patients the dimensions 'size' and 'weight' were the most affected, the KS patients had the most difficulties in estimating time questions.

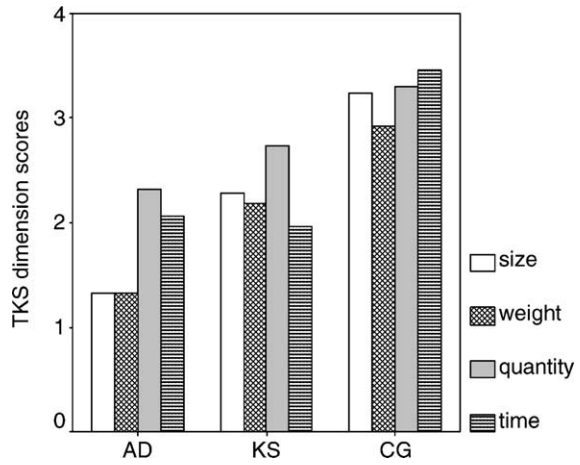

Fig. 2. Scores of the three groups in the different dimensions of the TKS.

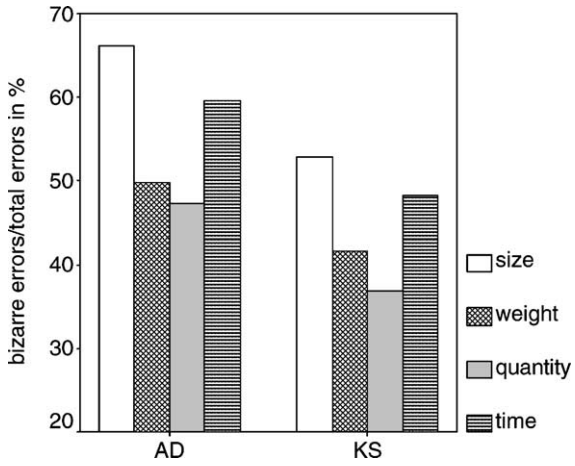

Fig. 3. Bizarre errors related to total errors in the dimensions of the TKS in AD and KS patients.

3.2.1. Bizarre errors

For a detailed analysis of the errors made by the patient groups we defined 'bizarre errors' as answers below or above *two* standard deviations of the mean of the norm group answers (see [3]) (e.g. for the item 'fly' outside of the range of 0.5–3 cm). Both patient groups showed significantly more bizarre errors in the TKS than the CG (AD: median = 5(1–10); KS: median = 3 (0–10); CG: median = 1 (0–4); $H = 72.5$, $P < 0.001$) and the AD patients were more impaired than the KS group ($U = 694.5$, $P < 0.001$).[1] The AD and KS patients produced such errors in all four dimensions. Fig. 3 shows the patients' profile of the percentage of bizarre errors relative to total errors in the four dimensions.

An analysis of variance with repeated measures for the patient groups' bizarre errors revealed a significant effect for dimensions ($F = 3.1$, $P = 0.02$) but no interaction of dimension and group ($F = 0.06$, $P = 0.98$). In both patient groups the dimensions 'size' and 'time' were more susceptible to bizarre errors than the dimensions 'weight' and 'quantity'. Examples for bizarre errors of the AD and KS patients are shown in Table 3.

3.2.2. Units of measurement

In the dimension 'quantity' no units of measurement are necessary. In the other dimensions ('size', 'weight' and 'time') both patient groups, but not the CG, produced units of measurement errors (UMEs).[2] For a differentiated analysis of UMEs we defined two types of possible UMEs: (A) unusual unit of the correct dimension (e.g. 'gram' for the weight of a car) and (B) unit of an incorrect dimension (e.g. 'metres' for the weight of a car).

The AD patients exhibited more UMEs than the KS patients (type A and B together) (AD: mean = 1.7, S.D. =

[1] Neither for the total group, nor for each separate group, there was an effect of age, gender and education for the production of bizarre errors.

[2] Again, neither for the total group, nor for each separate group, there was an effect of age, gender and education for the production of UMEs.

Table 3
Examples for bizarre errors in the TKS in AD and KS patients

Dimension/item	Correct range	Example for underestimation	Example for overestimation
Size			
Indoor plant	70–160 cm	10 cm (KS)	17 m (AD)
Crane	14–36 m	15 cm (AD)	1000 m (KS)
Fly	8–24 mm	0.1 mm (KS)	10 m (AD)
Cupboard	1.05–1.51 m	60 cm (AD)	20 m (AD)
Weight			
Glasses	24–130 g	1 g (KS)	25 kg (AD)
Armoire	25–90 kg	4 lb (AD)	1 t (KS)
Rat	100–500 g	8 g (KS)	35 kg (AD)
Car	500–1500 kg	4 kg (AD)	15 t (KS)
Quantity			
Paperclips	40–100	20 (AD)	250 (AD)
Flowers	15–31	4 (KS)	1000 (AD)
Eggs	10–14	5 (AD)	20 (KS)
Matches	20–28	10 (AD)	50 (KS)
Time			
Hamburg–Munich by train	6–11 h	1.5 h (KS)	1.5 days (AD)
Morning shower	3–12 min	15 s (KS)	2 h (AD)
Frankfurt–New York by plane	6–12 h	2.5 h (AD)	1 week (AD)
Ball falling from 10 m	0.5–6 s	0.1 s (AD)	7 min (KS)

1.5; KS: mean = 0.5, S.D. = 0.4; $T = 3.4$, $P < 0.001$). For the number of correct units in the different dimensions of the TKS there was an effect for dimension in an analysis of variance with repeated measures ($F = 25.6$, $P < 0.001$) and an interaction of dimension and group ($F = 3.1$, $P = 0.04$).

Both patient groups had the least difficulty with the dimension size and the most with the dimension 'time' but the inter-dimension differences were stronger in the AD group than in the KS patients ($T = 2.3$; $P = 0.02$). Interestingly, the first one (type A) was found in both patient groups whereas the second one (type B) was only produced by three of the AD patients.

3.2.3. Correlations

In all three groups the performance in the TKS (total score) correlated significantly with general knowledge (subtest information of the HAWIE-R: AD: $R = 0.28$, $P < 0.05$; KS: $R = 0.46$, $P < 0.01$; CG: $R = 0.32$, $P < 0.05$). In AD patients the TKS total score also correlated with severity of dementia (MMSE: $R = 0.43$, $P < 0.01$; CDR: $\rho = -0.29$, $P < 0.05$). No other correlation was significant.

The correlations of bizarre errors and UMEs are shown in Table 4. In both patient groups the quantity of bizarre errors was significantly related to general knowledge (subtest information of the HAWIE-R), working memory (digit span reverse), and verbal fluency (FAS-test). In AD patients there was an additional correlation to the severity of dementia (MMSE). In the KS group bizarre errors were correlated with short-term memory (immediate recall in a selective reminding task (Memo-test) and digit span forward), visuo-spatial memory (Corsi's block span), visuo-constructive abilities (copy of the Rey–Osterrieth–Figure) and with speed of information processing and interference (Word-Colour-test of the NAI). In both patient groups the quantity of bizarre errors was highly correlated to the performance in the TKS.

In AD patients the quantity of UMEs (types A and B combined) was only correlated to general knowledge (subtest information of the HAWIE-R) and to the TKS total score. There were no relations to any other neuropsychological function or severity of dementia. In KS patients the UMEs also correlated with general knowledge (subtest information of the HAWIE-R) and the TKS total score. In addition, it also correlated with working memory (digit span reverse), verbal fluency (FAS-test), speed of information processing and interference (Word-Colour-test of the NAI) and the sum of bizarre errors in the TKS.

4. Discussion

In our study, both patient groups were significantly impaired in cognitive estimation compared to the controls. The AD patients showed more pronounced deficits, while the KS group performed on a level between the AD patients and the CG. Previous studies have described divergent group profiles. Kopelman [22] revealed impairments in cognitive estimation in AD and KS patients as well, but there was no significant difference between the two patient groups. Taylor and O'Carroll [50] confirmed the deficits in cognitive estimation in both patient groups but they detected stronger impairments in the KS group than in the demented patients (AD and other aetiologies). The use of different tests to assess cognitive estimation may explain the deviation of our results from those of other studies. Kopelman [22] as well

Table 4
Correlations of bizarre errors and UMEs (types A and B) in the TKS and other neuropsychological tests

	AD, bizarre errors	KS, bizarre errors	AD, UMEs	KS, UMEs
MMSE	−0.41**	−0.13	−0.28	0.06
CDR	0.25	0.32*	0.06	0.16
Memo				
Immediate recall	0.01	−0.34*	−0.31	−0.10
Delayed recall	−0.16	−0.20	−0.23	−0.03
Digit span				
Forward	−0.16	−0.33*	0.03	−0.22
Reverse	−0.30*	−0.34*	−0.14	−0.37**
Corsi's block span	−0.05	−0.29*	−0.07	0.02
CERAD visuo-constructive	0.01	NA	−0.06	NA
Rey–Osterrieth–Figure				
Copy	NA	−0.59**	NA	−0.27
Delayed recall		0.05		−0.17
FAS-test				
Total	−0.29*	−0.41**	−0.30	−0.29*
AAT				
Auditory	−0.04	NA	−0.13	NA
Reading comprehension	−0.05		−0.09	
FWT				
Words	0.14	0.36*	−0.17	0.26
Colours	0.05	0.44*	−0.07	0.30*
Interference	0.02	0.31*	0.15	0.41**
Interference-colours	0.03	0.23	0.17	0.33*
WCST				
Correct	NA	−0.08	NA	0.07
Errors		0.15		0.01
Perseverations		0.26		0.01
LPS (reasoning)				
Correct	NA	−0.25	NA	−0.28
Estimated IQ				−0.27
HAWIE-R				
Information	−0.37**	−0.47**	−0.50**	−0.51**
TKS total score	−0.75**	−0.70**	−0.34*	−0.34*
TKS bizarre errors			0.23	0.47**

NA: not administered.
* $P < 0.05$ (two tailed).
** $P < 0.01$ (two tailed).

as Taylor and O'Carroll [50] used the CET (or a modified version of the CET), developed by Shallice and Evans [42]. The CET's construction and applied dimensions differ from the TKS, which was developed for our study (see the mentioned description of both instruments).

A further reason for the divergent results may be the different general cognitive status of the patient groups in all studies. The AD patients, examined here, were generally more impaired than the KS group in all tested cognitive domains contrasting to the previously mentioned studies.

As has been reported, the dimension 'quantity' was less affected than other cognitive estimation dimensions for both groups. This result may be due to the fact that within the dimension 'quantity' units of measurement are not required to substantiate the estimates while in all other tested dimensions ('size', 'weight' and 'time') a unit is necessary to constitute a correct solution (e.g. seconds or minutes in the dimension 'time'). Thus, the latter dimensions may comprise a further source of errors in choosing the correct unit (see discussion below). A second reason for the ease of quantity estimates could be that comprehension of quantities may be an inherent skill also occurring in infants and animals [6,33,51,57]. As illustrated by the "first in, last out phenomenon" observed in AD patients [2], a capacity which is inherent or learned at a very young age should be protected from loss for a long time even in cases of brain damages, such as in AD and KS. While the easiest dimension is the same in both patient groups, there are differences regarding the most demanding dimension(s). In AD patients, the dimensions 'size' and 'weight' are more impaired than

the others, while the KS group showed the most pronounced deficits in time estimations. Disturbances in the sense of time are one of the principal symptoms of the KS (see [53] for a review). This result corresponds with the findings of other studies [21,28,43] that describe time estimation deficits in KS patients. Mimura et al. [28] argue that in KS patients an internal clock may be inactive or that deficits in episodic memory cause disturbances in time estimation (specifically for intervals longer than 60 s). All these studies used subjective temporal judgement tasks (e.g. judgements of intervals of 10, 20, 30 and 60 s) in which the subjects are not asked to estimate the duration of specific events. In contrast, in the TKS subjects do not experience time intervals in the test situation. Thus, the TKS items require the retrieval of information from the semantic and/or episodic memory system, namely knowledge about the duration of the questioned or comparable events, about numbers and units of measurement or specific episodes related to the TKS item (e.g. last morning shower). The high correlation between the TKS performance and general knowledge leads to the assumption that the time items of the TKS are presumably more closely related to semantic memory than the subjective judgement tasks. In summary, the deficits of KS patients in estimating time intervals (both the abstract intervals used in temporal judgement tasks and the duration of specific events as asked in the TKS) may depend on timing deficits combined with impairments in semantic (and may be episodic) memory.

Both patient groups, but not the controls, produced bizarre errors in the TKS. They showed these error types in all dimensions with stronger impairments in ‘size’ and ‘time’. General knowledge is correlated with both performance in the TKS and the quantity of bizarre errors. Bizarre errors are also correlated to working memory and executive functions. Thus, general knowledge seems to be the best predictor of performance in cognitive estimation, and executive dysfunction seems to play an important role in the production of bizarre errors. According to the suggestion of Taylor and O’Carroll [50] KS patients may produce an immediate response which has not been ‘error checked’. Executive functions can therefore be considered responsible for checking the plausibility of generated answers. In line with this, Taylor and O’Carroll [50] argued that the deficits in cognitive estimation of KS patients could be caused by impaired semantic memory and disturbed response monitoring, associated with a tendency to confabulate. Though discussed controversially, a sample of studies pointed out that KS patients can have semantic memory deficits (e.g. [8,25,44]) and executive dysfunctions as well (e.g. [18,22]). The correlations described in our study support the suggestion that the deficits in cognitive estimation in KS patients are determined by semantic memory impairments and executive dysfunction. The poor performance of the AD patients in the TKS can largely be explained by the same arguments for AD patients are known to exhibit pronounced impairments in semantic memory (e.g. [9,13,15,24,30,37]) and executive functions (e.g. [38,39]).

The analysis of unit of measurement errors (UMEs) supports the integral role of semantic memory in cognitive estimation. Both patient groups, but not the controls, produced UMEs with AD patients being the most impaired. The disturbed recall of units from the semantic memory system has been almost neglected in other studies but this seems to be an important component of cognitive estimation deficits. If patients are unable to recall the correct unit, the solution is inevitably incorrect. To analyse the UMEs, two different types were differentiated: errors within the correct dimension (A) and units of the wrong dimension (B). Both patient groups produced type A errors while type B errors were observed only in a few AD patients (MMSE = 24, 22, and 19, respectively). Other AD patients, even with a lower MMSE score, did not produce such errors. Both error types can either be explained by a semantic memory deficit or by a tendency to perseverate which can be seen, for instance, in the answers of a KS patient in the dimension ‘weight’: glasses = 1 g; armoire = 50 g; rat = 50 g; car = 500 g. Even in the case of type A errors, a solution may be correct if the patient chooses an adequate number. For example one could say that the weight of glasses is 0.1 kg. The unit would be unusual but the complete answer would be correct. In the case of type B errors, the answer is incorrect by any means (e.g. the AD patients’ estimate of the weight of a rat as 12 km). Ilk of that errors can also be explained by a tendency to perseverate from one of the other dimensions and furthermore by a disturbed recall from the semantic memory system. It may further be important to recall episodes in which the dimensions in question were used or were of importance. As both AD and KS patients have particular problems in the episodic memory domain, cognitive estimation deficits can be caused by an episodic memory retrieval failure, even if this was not detected in our study.

A further component which may be involved in the production of UMEs (types A and B combined) is a failure in checking the plausibility of generated answers. Support for this suggestion is indicated by the correlations between quantity of UMEs and executive functions in KS patients. The production of UMEs may be comparable to specific, so-called ‘intrusion errors’ [10] or ‘shift errors’ [19] of AD patients in number transcoding. Another explanation for these error types may be a tendency to perseverate or deficiencies in set shifting and cognitive flexibility.

A synthesis of previous findings as well as the results of this study is provided in a model of cognitive estimation as proposed by Brand et al. [4]. The model is presented in Fig. 4.

Brand et al. [4] suggest that a cognitive estimation task first activates the working memory (WM). Once the task is represented in the WM, the declarative long-term memory (DLTM) and a central processing control (CPC) are activated. All information pertaining to the task (about subjects of estimation, necessary numbers and units, and strategies for solving the task) is drawn from the DLTM. The CPC identifies the information necessary for solving the task.

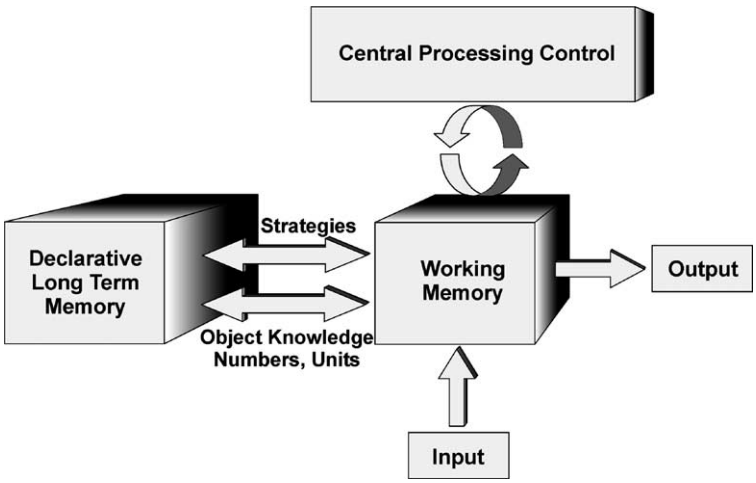

Fig. 4. A model of cognitive estimation (modified from [4]).

Then the WM uses the information and applies the strategies to formulate a possible solution. This solution is further evaluated for plausibility and accuracy in a feedback loop between the CPC and the WM. If no errors are detected, the CPC decides which of the available solutions is the best. Then the solution is transferred from the WM into the appropriate output code.

The findings of our study support the suggestions of the described model. In AD patients as well as in the KS group, performance in the TKS was related to general knowledge. In addition, the production of bizarre errors mainly depended on impairments in general knowledge, working memory deficits and executive dysfunctions, as indicated by the reported correlations.

5. Conclusion

AD and KS patients are impaired in cognitive estimation and eventually their estimates are bizarre. The deficits can be explained by a disturbed recall from the semantic memory system. The production of bizarre errors may depend on semantic memory deficits, working memory impairments and executive dysfunctions, such as a disturbed plausibility check. Further studies must examine the contribution of capacity in number and unit processing as well as recall of detailed information from the episodic memory system to cognitive estimation. These findings will help to expand the model of cognitive estimation.

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