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Cognitive functioning after whiplash injury: A meta-analysis

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Abstract

Complaints on cognitive functioning are often reported in patients suffering from whiplash syndrome, although objective neuropsychological test results do not always support these. In addition, radiological abnormalities and anatomical lesions are found only in a minority of these patients. This has led to a controversy about its existence in the literature. In this systematic review, the results of 22 neuropsychological studies on whiplash were quantitatively analyzed, focusing on working memory, attention, immediate and delayed recall, visuomotor tracking, and cognitive flexibility. Our findings suggest that a consistent overall pattern of cognitive dysfunction can be demonstrated after whiplash injury through neuropsychological testing, both compared to healthy and to asymptomatic controls. Six months after the accident, improvement is found in working memory, attention, immediate recall, and visuomotor tracking. The results are discussed in the light of recent findings on the effect of cerebral dysfunction, malingering, pain-related factors, and the role of coping strategies and posttraumatic stress on neuropsychological test performance. (*JINS*, 2000, *6*, 271–278.)

Keywords: Whiplash, Meta-analysis, Neuropsychological tests, Review

INTRODUCTION

Whiplash injury can occur after hyperflexion, hyperextension, or hyperlateroversion of the neck, often caused by rear-end car accidents. This can lead to a number of complaints, if there is no external head injury or loss of consciousness, known as the whiplash syndrome (Fischer et al., 1995, 1997). Since most patients diagnosed with whiplash fully recover after 2 to 3 months, it is regarded as a benign disorder (Barnsley et al., 1994). However, in a number of patients the complaints still exist 6 months after the accident, resulting in a fairly high disability rate (Spitzer et al., 1995). Estimates of the proportion of patients that will develop long-lasting symptoms, usually referred to as the late whiplash syndrome, vary from 14 to 88% (Barnsley et al., 1994). Whiplash patients show various complaints, which can be physical (such as neck and shoulder pain, dizziness, and visual problems), cognitive (i.e., attention and memory disturbances), and psychological in nature, such as emotional lability (Radanov & Dvorak, 1996; Sturzenegger et al., 1994).

A major problem in diagnosing whiplash syndrome is the lack of objective data to support this diagnosis (Pearce, 1999). Imaging techniques such as CT or MRI often fail to demonstrate cerebral damage, whereas lesions in the ligaments or other soft-tissue sites are found only in a small subgroup of these patients. Generally, these techniques do not have a high prognostic value (Ronnen et al., 1996; Voyvodic et al., 1997). The standard neurological examination reveals no dysfunctions in most cases (Spitzer et al., 1995). This lack of objective data gave rise to the idea that the complaints seen in late whiplash patients are a result of neurosis (Hodge, 1971) or related to psychological disorder (Gargan et al., 1997). Other studies concluded that outcome expectancies (Radanov et al., 1993a; Schrader et al., 1996) or litigation status (Obelieniene et al., 1999; Swartzman et al., 1996) are important determinants of the symptoms seen after whiplash injury, although brain injury cannot be fully excluded (Alexander, 1998).

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A considerable amount of research has been done in the field of neuropsychology with respect to the cognitive problems after a whiplash injury. Some of these studies found attentional dysfunction—mainly disorders of divided attention—or memory disturbances (Ettlin et al., 1992), while others did not always find abnormal neuropsychological functioning in chronic whiplash patients (Radanov et al., 1993b). The aim of this study was to examine the precise pattern and magnitude of cognitive impairment after whiplash injury by meta-analytically combining quantitative data from previous studies. More specifically, we focused on whiplash patients compared to healthy individuals, symptomatic *versus* asymptomatic individuals, and the course of cognitive function in time. By summarizing all the evidence on whiplash-associated cognitive malfunctioning, this quantitative review may prompt future research elucidating the mechanisms underlying such disturbances.

METHODS

Only published studies were selected by means of a literature search in PsycLit (1967–1999) and MedLine (1966–1999) using the keywords *whiplash*, *cognitive*, *attention*, and *memory*. Additional studies were identified by examining the list of references of these studies. Several inclusion criteria were applied in order to perform the quantitative analyses. First, the paper was an original article. Second, cognitive functioning was assessed using standard neuropsychological or reliable experimental testing methods. Third, test scores were presented for the experimental and control group (mean and standard deviation), or the exact p values, t values, or F values were given.

It was determined for each study which type of control group was used, healthy controls or other patient groups. In addition, the postaccident time was determined for the patient group as an indication of the chronicity of the symptoms. Subsequently, effect sizes (d) were calculated, that is, the standardized difference between the experimental group and the compared group. If no exact values were reported for nonsignificant results, these results were included as $d = 0.00$ in the analysis, adopting a conservative approach (Rosenthal, 1991). The direction of the effect size was negative if the performance of whiplash patients was worse than the control group. Calculations were performed independently by two authors (R.P.C.K. and A.A.). Differences in calculations were resolved by discussion, resulting in an interrater reliability of unity.

In the meta-analysis, a combined d value was calculated, expressing the magnitude of associations across studies. This d value was weighted for sample size, in order to correct for upwardly biased estimation of the effect in small sample sizes (Hedges & Olkin, 1985). In addition, Stouffer's Z weighting for sample size provided an indication of the significance of the difference in task performance between the whiplash and the control group. A 95% confidence interval was calculated on the basis of the standard error. Tests measuring the same cognitive construct were taken together in the analyses (as detailed in the Results section). Meta-analyses were performed separately for the difference between chronic whiplash patients *versus* healthy controls and for the difference between symptomatic patients *versus* participants who did not report any symptoms after a similar car accident (the asymptomatic group). In addition, meta-analyses were conducted on studies reporting follow-up data, with d values reflecting the difference between baseline performance and follow-up performance after a period of 6 months. An overall d value, in which all cognitive constructs were pooled, was computed first as a general index of differences in cognitive function. Hereafter, meta-analyses were performed for the cognitive constructs separately. All analyses were performed using the statistical package META (Schwarzer, 1988).

RESULTS

The literature search identified 22 studies on neuropsychological functioning after whiplash injury. Of these, three single-case reports were not included in the meta-analysis (Bohnen et al., 1993; Fisher, 1982; Hofstad & Gjerde, 1985). Other studies that were excluded did not report exact data on the test results (Berstad et al., 1975; Schwartz et al., 1987; Yarnell & Rossie, 1988) or did not have a control group (Keidel et al., 1992; Smed, 1997). Tables 1 and 2 display all studies that fulfilled the criteria, with corresponding effect sizes for the difference in performance between the whiplash and the control group. Only the studies listed in Table 1, comparing symptomatic whiplash patients to either an asymptomatic control group or healthy volunteers, were meta-analyzed. The study of Ettlin et al. (1992) was the only paper in which healthy controls were compared to individuals who were included on the basis of the injury rather than their symptoms. Moreover, these participants were tested within 1 week after the accident. Thus, this study could not be directly compared to studies that report data on symptomatic and chronic participants and was therefore excluded from the meta-analysis.

Other studies compared whiplash patients to other patient groups, such as patients suffering from rheumatism (Radanov et al., 1992b), chronic pain or head injury (Taylor et al., 1996), *lower cervical spine syndrome* (a syndrome characterized by cervical and cervicobrachial pain; see Radanov et al., 1992a), or "whiplash-like" symptoms (Olsnes, 1989), or divided the whiplash group into disabled and nondisabled patients (Radanov et al., 1993a). Chronic pain patients or patients with other symptoms similar to those reported by whiplash patients are appropriate control groups if one wants to control for the possible effects of these symptoms. However, these control groups vary considerably with respect to symptomatology and etiology. Moreover, a separate meta-analysis on these papers yielded a 95% confidence interval from -0.56 to 0.51. This also indicates that the control groups of these studies are indeed very heterogeneous. Averaging the d values of these studies and interpreting the results would thus not be suitable, both from a

Table 1. Summary of the neuropsychological studies that were included in the meta-analysis: post-accident time, type of control group, size experimental (N_E) and control group (N_C), reported neuropsychological tests, and associated effect sizes (d)

Study (year)	Whiplash group	Postaccident time	Control group	N_E	N_C	Neuropsychological test(s)	d
Radanov et al. (1990)	symptomatic	23.7 m (SD = 20.3)	healthy	58	52	PASAT	−1.13
Kischka et al. (1991)	symptomatic	not specified (“chronic”)	healthy	18	18	Digit span, forward	0.00[a]
						Stroop	−0.57
						Corsi, forward	−0.57
						Story recall, immediate	−0.57
						Story recall, delayed	0.00[a]
						Rey figure recall, delayed	0.00[a]
Radanov et al. (1993b)	symptomatic	7.3 d (SD = 3.9) + follow-up at 6 m	asymptomatic	31	67	Digit span, forward + backward	−0.63
						Corsi	−0.33
						Trail Making Test, A	−0.43
						Trail Making Test, B	−0.14
						Number Connection Test	−0.69
						PASAT	−0.51
Di Stefano et al. (1995)	symptomatic	7.0 d (SD = 4.5) + follow-up at 6 m + 12 m	asymptomatic	21	21	Digit span, forward + backward	−0.36
						Corsi	−0.36
						Number Connection Test	−0.99
						Trail Making Test, A	−0.29
						Trail Making Test, B	−0.38
						PASAT	−0.74
						CVLT, immediate	−0.45
						CVLT, delayed	−0.53
Di Stefano et al. (1996)	symptomatic	7.3 d (SD = 4.0) + follow-up at 6 m	asymptomatic	28	58	Digit span, forward + backward	−0.44
						Corsi	−0.27
						Trail Making Test, A	−0.23
						Trail Making Test, B	0.00
						Number Connection Test	−0.47
						PASAT	−0.20
						CVLT, immediate	−0.12
						CVLT, delayed	−0.18
			healthy	28	11	Digit span, forward + backward	−1.28
						Corsi	−0.37
						Trail Making Test, A	−0.14
						Trail Making Test, B	−0.60
						Number Connection Test	−0.89
						PASAT	−0.79
						CVLT, immediate	−0.32
						CVLT, delayed	−0.31
Gimse et al. (1997)	symptomatic	1–4 y	healthy	23	23	PASAT	−0.47
						Trail Making Test, A	−0.23
						Trail Making Test, B	−0.39
						AVLT, immediate	−0.85
						AVLT, delayed	−0.91
Kessels et al. (1998)	symptomatic	1–5 y	healthy	24	21	PASAT	−0.85
Schmand et al. (1998)	symptomatic	24 m (SD = 22)	healthy	108	46	Stroop	−0.67
						Trail Making Test, A	−0.65
						Trail Making Test, B	−0.82
						AVLT, immediate	−1.23
						AVLT, delayed	−1.17

Note. d = days; m = months; y = years; PASAT = Paced Auditory Serial Addition Task; CVLT = California Verbal Learning Test; AVLT = Auditory Verbal Learning Test.
[a]Exact data for this test were not reported, only that the p value was not significant. Following a conservative approach, a d value of 0.00 was used in the meta-analysis.

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Table 2. Characteristics of studies on neuropsychological functioning after whiplash injury that were excluded from the meta-analysis due to heterogeneity of the used control groups: postaccident time, type of control group, size of experimental (N_E) and control group (N_C), reported neuropsychological tests, and associated effect sizes (d)

Study (year)	Whiplash group	Postaccident time	Control group	N_E	N_C	Neuropsychological test(s)	d
Olsnes (1989)	symptomatic	6–18 m	whiplash-like symptoms	34	21	Digit span, forward + backward	−0.35
						Trail Making Test, A	0.08
						Trail Making Test, B	−0.07
Radanov et al. (1992a)	symptomatic	27 m (SD = 23.8)	lower cervical spine syndrome	30	15	Number Connection Test	−0.57
						PASAT	−1.05
Radanov et al. (1992b)	symptomatic	24.6 m (SD = 22.7)	rheumatism	54	28	Number Connection Test	1.01
						PASAT	−0.02
Ettlin et al. (1992)	unselected	3–7 d	healthy	21	21	Digit span, forward	−1.30
						Digit span, backward	−1.11
						Stroop	−0.53
						Corsi, forward	−0.14
						Corsi, backward	−0.77
						Story recall, immediate	−0.56
						Story recall, delayed	−0.94
						Rey figure recall, delayed	−0.47
Radanov et al. (1993a)	disabled	5.3 d (SD = 1.5) + follow-up at 6 m	nondisabled whiplash	6	91	Digit span	−0.16
						Corsi	−1.06
						Number Connection Test	−0.99
						Trail Making Test, A	−0.90
						Trail Making Test, B	−0.27
						PASAT	−0.10
Taylor et al. (1996)	symptomatic	> 4 y	chronic pain	15	24	Digit span, forward	−0.74
						Digit span, backward	−0.75
						Visual span, forward	−0.39
						Visual span, backward	−0.05
						PASAT	0.53
			head injury	15	10	Digit span, forward	−0.78
						Digit span, backward	−0.50
						Visual span, forward	−0.20
						Visual span, backward	−0.07
						PASAT	−0.11

conceptual and a statistical point of view; therefore, these studies were not included in the meta-analysis. The effect sizes for the studies that were excluded from the meta-analysis are listed in Table 2.

The neuropsychological tests used in these studies were divided into a number of subgroups that measure approximately the same cognitive construct. The construct *working memory* was measured verbally with the Digit Span (Wechsler, 1945, 1955) and nonverbally with the Corsi Block-Tapping Test (Berch et al., 1998) or Visual Memory Span (Wechsler, 1987). The construct *attention* was assessed with the Paced Auditory Serial Addition Task (PASAT, described by Gronwall, 1977) and the Stroop Color Word Test (Stroop, 1935), the first measuring divided and sustained attention, while the latter can be seen as a measure of selective attention and susceptibility for interference. The construct *immediate recall* was tested with Story Recall of the Wechsler Memory Scale (Wechsler, 1945), or by using word lists, such as the California Verbal Learning Test (CVLT; Delis et al., 1987) and the Rey Auditory Verbal Learning Test (AVLT; Rey, 1964). The construct *delayed recall* was measured with the delayed test performance on Story Recall, the CVLT and the AVLT, and with the help of the Rey–Osterrieth Complex Figure Test (a test of nonverbal delayed memory functioning; Rey, 1941). The Number Connection Test (Oswald & Roth, 1987) and the Trail Making Test part A were included in the construct *visuomotor tracking*, whereas the Trail Making Test part B can be regarded as an index of the construct *cognitive flexibility* (see Corrigan & Hinkeldey, 1987, for a description of the Trail Making Test).

Thus, the following cognitive functions were included as variables in the meta-analysis: working memory, attention, immediate recall, delayed recall, visuomotor tracking, and cognitive flexibility. Table 3 shows the results of the meta-

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Table 3. Results of the meta-analyses on cognitive functioning in whiplash patients compared to normal and asymptomatic control groups

Cognitive function	*k*	*N*	*d*	*Z*	95% *CI*
Chronic whiplash patients *vs*. healthy controls					
Overall	6	430	−0.82	−7.5****	−1.03–−0.60
Working memory	2	75	−0.53	−2.0*	−1.04–−0.01
Attention	6	430	−0.78	−7.4****	−0.98–−0.57
Immediate recall	4	275	−0.83	−4.4****	−1.20–−0.46
Delayed recall	4	275	−0.64	−2.4***	−1.16–−0.12
Visuomotor tracking	3	239	−0.53	−3.7****	−0.81–−0.25
Cognitive flexibility	3	239	−0.68	−4.8****	−0.96–−0.40
Sub-acute symptomatic patients *vs*. asymptomatic controls					
Overall	3	226	−0.38	−2.69**	−0.66–−0.10
Working memory	3	226	−0.41	−2.9**	−0.68–−0.13
Attention	3	226	−0.43	−3.0**	−0.72–−0.15
Immediate recall	2	128	−0.23	−1.25	−0.60–0.13
Delayed recall	2	128	−0.30	−1.6	−0.66–0.07
Visuomotor tracking	3	226	−0.39	−2.7**	−0.67–−0.11
Cognitive flexibility	3	226	−0.13	−0.96	−0.41–0.14

Note. k = number of studies; N = total number of subjects; d = mean weighted effect size; 95% CI = 95% confidence interval.
$^*p < 0.05$; $^{**}p < 0.01$, $^{***}p < 0.001$, $^{****}p < 0.0001$.

analysis of chronic symptomatic whiplash patients compared to healthy controls. Also reported is the meta-analysis of subacute whiplash patients compared to participants who did not report any symptoms after a rear-end collision (asymptomatic controls). Table 4 lists the results of the meta-analysis on the course of the cognitive functioning between subacute baseline testing and 6 months after the accident.

Compared to normal controls, the chronic whiplash group demonstrated a significant overall lowered performance, as well as impairments on all six cognitive domains separately. According to the nomenclature of Cohen (1988) most effect sizes are in the *moderate* range ($d = 0.60$). The effect sizes for attention ($d = -0.78$, six studies, 430 participants) and immediate recall ($d = -0.83$, four studies, 275 participants) approach a *large* difference ($d = 0.80$). Table 3 also shows that symptomatic whiplash patients perform worse than a group of asymptomatic participants after a rear-end collision on tests of working memory, attention, and visuomotor tracking when tested within 2 weeks after the injury (subacute symptomatic patients).

Furthermore, cognitive functioning changed over time in whiplash patients: Working memory, attention, immediate recall, and visuomotor tracking showed significant improvement 6 months after the accident compared to a subacute baseline testing. No improvement was found in delayed recall and in cognitive flexibility. Only in one study (Di Stefano & Radanov, 1996) was the whiplash group compared to normal controls 6 months postonset. Here, attentional functioning was still lower in the patient group than in healthy controls ($d = -0.69$, $p < .04$). This indicates that although attention improved in the course of time, whiplash patients performed worse than healthy controls.

Table 4. Course in time of cognitive functioning in symptomatic whiplash patients (6 months postaccident compared to subacute stage)

Cognitive function	*k*	*N*	*d*	*Z*	95% *CI*
Overall	3	160	0.36	2.2**	0.04–0.67
Working memory	3	160	0.26	1.7*	−0.05–0.57
Attention	3	160	0.62	3.8***	0.30–0.94
Immediate recall	2	98	0.41	2.0*	0.02–0.81
Delayed recall	2	98	0.18	0.9	−0.22–0.57
Visuomotor tracking	3	160	0.47	2.9**	0.15–0.78
Cognitive flexibility	3	160	0.13	0.8	−0.18–0.44

Note. k = number of studies; N = total number of subjects; d = mean weighted effect size; 95% CI = 95% confidence interval.
$^*p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.0001$.

DISCUSSION

The present meta-analysis shows that chronic, symptomatic whiplash patients, compared to healthy controls, have significant problems on tests of working memory, attention, immediate and delayed recall, visuomotor tracking, and cognitive flexibility. When comparing symptomatic whiplash patients to subjects who do not report (cognitive) symptoms after a rear-end collision, the symptomatic group has significantly lower scores on tests of working memory, attention, and visuomotor tracking when measured shortly after the accident. These results indicate that the subjective complaints about cognitive deterioration, as reported by many whiplash patients, can be consistently and objec-

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tively demonstrated with the help of standardized neuropsychological tests.

When looking at the pattern of dysfunction in chronic symptomatic patients compared to healthy controls, an overall impaired test performance becomes apparent. After comparing symptomatic with asymptomatic subjects in the postacute phase, lower scores on tests measuring working memory, attention, and visuomotor tracking are found, although the differences are less significant than compared to healthy controls. Analysis of the course of cognitive impairment in time shows that scores on tests for working memory, attention, immediate recall, and visuomotor tracking are significantly improved in symptomatic patients 6 months after the accident, compared to the subacute stage. Delayed recall and cognitive flexibility test scores do not differ at these two time points.

In sum, a general pattern of cognitive dysfunction can be demonstrated in symptomatic whiplash patients, compared to asymptomatic controls, as well as compared to healthy participants. Six months after the trauma, significant improvement is found in tasks of working memory, attention, immediate recall, and cognitive flexibility, whereas delayed recall and cognitive flexibility do not change in this period of time.

This is the first meta-analysis on neuropsychological findings after whiplash injury. Our results corroborate and extend a previous narrative review (Radanov & Dvorak, 1996), suggesting a nonspecific pattern of cognitive dysfunction after whiplash injury. Although clear improvements can be found over time, long-lasting cognitive complaints can still be present. An advantage of a meta-analytical approach is that it does not suffer from several shortcomings of traditional qualitative narrative reviews. In simply vote counting significant *versus* nonsignificant results, the subjective role of the reviewer might be relatively strong. Also, the precise magnitude of the effect is not specified, and the lack of weighting by sample size might result in distortion of overall trends in data across studies. A limitation of the present study concerns the small number of studies included in some of the analyses, although we included more studies than were used in previous reviews. Furthermore, it should be mentioned that the classification of tests into specific cognitive domains remains arbitrary to some degree. More research, including quantitative measures of possible moderators of effect size (such as pain or psychological distress) is needed in this field, before an even more thorough meta-analysis can be carried out.

The findings of the present meta-analysis do not address the origin of the cognitive complaints seen after whiplash injury. Although impairments on neuropsychological tests do not have to be the result of neurologic deficits (Mathews et al., 1966), cerebral dysfunction might be a possible explanation for the symptoms of whiplash patients. However, convincing evidence supporting this has not been found, even with the help of modern imaging techniques such as PET or SPECT (Bicik et al., 1998; Radanov et al., 1999). Furthermore, the use of medication can influence test performance and thus cannot be excluded as a putative confounding factor (Radanov et al., 1993b). For example, Di Stefano and Radanov (1995) found that in a group of subacute, symptomatic whiplash patients 80% of the participants used medication that could potentially have effects on the cognitive test performance. However, there is only one study in which medicated and unmedicated whiplash patients were directly compared (Gimse et al., 1997). Here, no differences were found in neuropsychological test performance between these two groups.

In addition, damage to the cervical spine, for example the zygapophysial joints, might be related to the complaints reported by whiplash patients, such as pain of the neck (Barnsley et al., 1995), but the exact impact of the flexion–extension mechanisms is not clear (Gargan, 1995; Yoganandan et al., 1999). However, although the absence of objective organic signs precludes the treatment of possible neurologic consequences, assessment and perhaps treatment of psychological impairment is of course still important (Alexander, 1998).

Due to the lack of objective signs to support the diagnosis and because of financial gain (cf. Binder & Rohling, 1996; Rohling et al., 1995), a high impact of malingering is suspected in whiplash patients. Recently, malingering has indeed been demonstrated in some whiplash patients, and was more frequent in patients seeking financial compensation (Schmand et al., 1998). However, it is very difficult to distinguish malingering from underperformance due to other reasons, such as psychiatric problems (Schagen et al., 1997).

The presence of chronic pain might also contribute to impaired cognitive and psychological functioning, even in the absence of brain damage (Iverson & McCracken, 1997; Lees-Haley & Brown, 1993). High levels of pain are reported by many whiplash patients (Wallis et al., 1996) and have been linked to cognitive dysfunction in this group (Radanov et al., 1992b; Schwartz et al., 1987). In addition, these patients suffer from injury they do not feel themselves responsible for, since the whiplash syndrome is most common after a rear-end collision. This, in combination with the strain resulting from chronic pain (cf. Skevington, 1995), might interfere with normal coping strategies. Post-traumatic stress (see Jaspers, 1998, for a review) or depression (Lee et al., 1993; Taylor et al., 1996) could be the result, possibly leading to a lower performance on cognitive tests.

In conclusion, our quantitative analysis of the published data from the literature provides strong evidence that cognitive complaints after whiplash injury are not limited to subjective reports, but extend to malperformance on objective, standardized tests. This finding calls for future research on the putative mechanisms underlying these dysfunctions. Pain and, in some individuals, malingering are possible factors that may play a role in explaining the cognitive symptoms observed after whiplash injury. Moreover, failure to use effective coping strategies may lead to post-traumatic stress-like symptoms or perhaps depression. The precise interactions of these factors, however, remain unclear, since it was not possible to perform a meta-analysis on these variables as well, due to the small number of stud-

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ies. Also, the clinical nature of the studies included in the meta-analysis prevents ruling out pre-existing and unrelated problems as a contributing factor. Clearly, more and certainly more detailed research is needed before strong final conclusions can be reached about the underlying mechanisms.

REFERENCES[1]

Alexander, M.P. (1998). In the pursuit of proof of brain damage after whiplash injury. *Neurology*, *51*, 336–340.

Barnsley, L., Lord, S., & Bogduk, N. (1994). Whiplash injury. *Pain*, *58*, 283–307.

Barnsley, L., Lord, S.M., Wallis, B.J., & Bogduk, N. (1995). The prevalence of chronic cervical zygapophysial joint pain after whiplash. *Spine*, *20*, 20–25.

Berch, D.B., Krikorian, R., & Huha, E.M. (1998). The Corsi Block-Tapping Task: Methodological and theoretical considerations. *Brain and Cognition*, *38*, 317–338.

Berstad, J.R., Bærum, B., Löchen, E.A., Mogstad, T.E, & Sjaastad, O. (1975). Whiplash: Chronic organic brain syndrome without hydrocephalus ex vacuo. *Acta Neurologica Scandinavica*, *51*, 268–284.

Bicik, I., Radanov, B.P., Schäfer, N., Dvorak, J., Blum, B., Weber, B., Burger, C., Von Schulthess, G.K., & Buck, A. (1998). PET with ^{18}fluorodeoxyglucose and hexamethylpropylene amine oxime SPECT in late whiplash syndrome. *Neurology*, *51*, 345–350.

Binder, L.M. & Rohling, M.L. (1996). Money matters: A meta-analytic review of the effects of financial incentives on recovery after closed-head injury. *American Journal of Psychiatry*, *153*, 7–10.

Bohnen, N.I., Jolles, J., & Verhey, F.R. (1993). Persistent neuropsychological deficits in cervical whiplash patients without direct headstrike. *Acta Neurologica Belgica*, *93*, 23–31.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Erlbaum.

Corrigan, J.D. & Hinkeldey, N.S. (1987). Relationships between parts A and B of the Trail Making Test. *Journal of Clinical Psychology*, *43*, 402–408.

Delis, D.C., Kramer, J.H., Kaplan, E., & Ober, B.A. (1987). *California Verbal Learning Test: Adult version*. San Antonio, TX: The Psychological Corporation.

*Di Stefano, G. & Radanov, B.P. (1995). Course of attention and memory after common whiplash: A two-years prospective study with age, education and gender pair-matched patients. *Acta Neurologica Scandinavica*, *91*, 346–352.

*Di Stefano, G. & Radanov, B.P. (1996). Quantitative and qualitative aspects of learning and memory in common whiplash patients: A 6-month follow-up study. *Archives of Clinical Neuropsychology*, *11*, 661–676.

Ettlin, T.M., Kischka, U., Reichmann, S., Radii, E.W., Heim, S., à Wengen, D., & Benson, D.F. (1992). Cerebral symptoms after whiplash injury of the neck: A prospective clinical and neuropsychological study of whiplash injury. *Journal of Neurology, Neurosurgery, and Psychiatry*, *55*, 943–948.

[1]References marked with an asterisk indicate studies included in the meta-analysis.

Fischer, A.J.E.M., Huygen, P.L.M., Folgering, H.T., & Verhagen, W.I.M. (1995). Vestibular hyperreactivity and hyperventilation after whiplash injury. *Journal of the Neurological Sciences*, *132*, 35–43.

Fischer, A.J.E.M., Verhagen, W.I.M., & Huygen, P.L.M. (1997). Whiplash injury: A clinical review with emphasis on neuro-otological aspects. *Clinical Otolaryngology*, *22*, 192–201.

Fisher, C.M. (1982). Whiplash amnesia. *Neurology*, *32*, 667–668.

Gargan, M.F. (1995). What is the evidence for an organic lesion in whiplash injury? *Journal of Psychosomatic Research*, *39*, 777–781.

Gargan, M., Bannister, G., Main, C., & Hollis, S. (1997). The behavioural response to whiplash injury. *Journal of Bone and Joint Surgery (British Volume)*, *79*, 523–526.

*Gimse, R., Björgen, I.A., Tjell, C., Tyssedal, J.S., & Bo, K. (1997). Reduced cognitive functions in a group of whiplash patients with demonstrated disturbances in the posture control system. *Journal of Clinical and Experimental Neuropsychology*, *19*, 838–849.

Gronwall, D.M.A. (1977). Paced Auditory Serial-Addition Task: A measure of recovery from concussion. *Perceptual and Motor Skills*, *44*, 367–373.

Hedges, L.V. & Olkin, I. (1985). *Statistical methods for meta-analysis*. Orlando, FL: Academic Press.

Hodge, J.R. (1971). The whiplash neurosis. *Psychosomatics*, *12*, 245–249.

Hofstad, H. & Gjerde, I.O. (1985). Transient global amnesia after whiplash trauma. *Journal of Neurology, Neurosurgery, and Psychiatry*, *48*, 956–957.

Iverson, G.L. & McCracken, L.M. (1997). 'Postconcussive' symptoms in persons with chronic pain. *Brain Injury*, *11*, 783–790.

Jaspers, J.P.C. (1998). Whiplash and post-traumatic stress disorder. *Disability and Rehabilitation*, *20*, 397–404.

Keidel, M., Yagüez, L., Wilhelm, H., & Diener, H.C. (1992). Prospektiver Verlauf neuropsychologischer Defizite nach zervicoenzephalem Akzelerationstrauma [Prospective follow-up of neuropsychological deficits after cervicocephalic acceleration trauma]. *Nervenarzt*, *63*, 731–740.

*Kessels, R.P.C., Keyser, A., Verhagen, W.I.M., & Van Luijtelaar, E.L.J.M. (1998). The whiplash syndrome: A psychophysiological and neuropsychological study towards attention. *Acta Neurologica Scandinavica*, *97*, 188–193.

*Kischka, U., Ettlin, T., Heim, S., & Schmid, G. (1991). Cerebral symptoms following whiplash injury. *European Neurology*, *31*, 136–140.

Lee, J., Giles, K., & Drummond, P.D. (1993). Psychological disturbances and an exaggerated response to pain in patients with whiplash injury. *Journal of Psychosomatic Research*, *37*, 105–110.

Lees-Haley, P.R. & Brown, R.S. (1993). Neuropsychological complaint base rates of 170 personal injury claimants. *Archives of Clinical Neuropsychology*, *8*, 203–209.

Mathews, C.G., Shaw, D.J., & Kløve, H. (1966). Psychological test performances in neurologic and "pseudo-neurologic" subjects. *Cortex*, *2*, 244–253.

Obelieniene, D., Schrader, H., Bovim, G., Miseviciene, I., & Sand, T. (1999). Pain after whiplash: A prospective controlled inception cohort study. *Journal of Neurology, Neurosurgery, and Psychiatry*, *66*, 279–283.

Olsnes, B.T. (1989). Neurobehavioral findings in whiplash patients with long-lasting symptoms. *Acta Neurologica Scandinavica*, *80*, 584–588.

Oswald, W.D. & Roth, E. (1987). *Der Zahlen-Verbindungs-Test (ZVT)* [The Number Connection Test (NCT)] (2nd ed.). Göttingen, Germany: Testzentrale.

Pearce, J.M.S. (1999). A critical appraisal of the chronic whiplash syndrome. *Journal of Neurology, Neurosurgery, and Psychiatry*, *66*, 273–276.

Radanov, B.P., Bicik, I., Dvorak, J., Antinnes, J., Von Schulthess, G.K., & Buck, A. (1999). Relation between neuropsychological and neuroimaging findings in patients with late whiplash syndrome. *Journal of Neurology, Neurosurgery, and Psychiatry*, *66*, 485–489.

Radanov, B.P., Di Stefano, G., Schnidrig, A., & Sturzenegger, M. (1993a). Psychological stress, cognitive performance and disability after common whiplash. *Journal of Psychosomatic Research*, *37*, 1–10.

*Radanov, B.P., Di Stefano, G., Schnidrig, A., Sturzenegger, M., & Augustiny, K.F. (1993b). Cognitive functioning after common whiplash: A controlled follow-up study. *Archives of Neurology*, *50*, 87–91.

Radanov, B.P. & Dvorak, J. (1996). Impaired cognitive functioning after whiplash injury of the cervical spine. *Spine*, *21*, 392–397.

Radanov, B.P., Dvorak, J., & Valach, L. (1992a). Cognitive deficits in patients after soft tissue injury of the cervical spine. *Spine*, *17*, 127–131.

Radanov, B.P., Hitlinger, I., Di Stefano, G., & Valach, L. (1992b). Attentional processing in cervical spine syndromes. *Acta Neurologica Scandinavica*, *85*, 358–362.

*Radanov, B.P., Valach, L., Wittlieb-Verpoort, E., & Dvorak, J. (1990). Neuropsychologische Befunde nach Schleuderverletzung der Halswirbelsäule [Neuropsychological findings following whiplash injury of the cervical spine]. *Schweizerische Medizinische Wochenschrift*, *120*, 704–708.

Rey, A. (1941). L'examen psychologique dans les cas d'encéphalopathie traumatique: Les problèmes [The psychological examination in cases of traumatic encephalopathy: Problems]. *Archives de Psychologie*, *28*, 215–285.

Rey, A. (1964). *L'examen clinique en psychologie* [Clinical assessment in psychology]. Paris: Presses Universitaires de France.

Rohling, M.L., Binder, L.M., & Langhinrichsen-Rohling, J. (1995). Money matters: A meta-analytic review of the association between financial compensation and the experience and treatment of chronic pain. *Health Psychology*, *14*, 537–547.

Ronnen, H.R., De Korte, P.J., Brink, P.R.G., Van der Bijl, H.J., Tonino, A.J., & Franke, C.L. (1996). Acute whiplash injury: Is there a role for MR imaging?—A prospective study of 100 patients. *Radiology*, *201*, 93–96.

Rosenthal, R. (1991). *Meta-analytic procedures for social research* (Rev. ed.). Newbury Park, CA: Sage.

Schagen, S., Schmand, B., De Sterke, S., & Lindeboom, J. (1997). Amsterdam Short-Term Memory Test: A new procedure for the detection of feigned memory deficits. *Journal of Clinical and Experimental Neuropsychology*, *19*, 43–51.

*Schmand, B., Lindeboom, J., Schagen, S., Heijt, R., Koene, T., & Hamburger, H.L. (1998). Cognitive complaints in patients after whiplash injury: The impact of malingering. *Journal of Neurology, Neurosurgery, and Psychiatry*, *64*, 339–343.

Schrader, H., Obelieniene, D., Bovim, G., Surkiene, D., Mickeviciene, D., Miseviciene, I., & Sand, T. (1996). Natural evolution of late whiplash syndrome outside the medicolegal context. *Lancet*, *347*, 1207–1211.

Schwartz, D.P., Barth, J.T., Dane, J.R., Drenan, S.E., DeGood, D.E., & Rowlingson, J.C. (1987). Cognitive deficits in chronic pain patients with and without history of head/neck injury: Development of a brief screening battery. *Clinical Journal of Pain*, *3*, 94–101.

Schwarzer, R. (1988). Meta-analysis programs. *Behavior Research Methods, Instruments, and Computers*, *20*, 338.

Skevington, S.M. (1995). *Psychology of pain*. Chichester, U.K.: John Wiley & Sons.

Smed, A. (1997). Cognitive function and distress after common whiplash injury. *Acta Neurologica Scandinavica*, *95*, 73–80.

Spitzer, W.O., Skovron, M.L., Salmi, L.R., Cassidy, J.D., Duranceau, J., Suissa, S., & Zeiss, E. (1995). Scientific monograph of the Quebec Task Force on Whiplash-Associated Disorders: Redefining "whiplash" and its management. *Spine*, *20*(Suppl. 8), 1S–73S.

Stroop, J.R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, *18*, 643–662.

Sturzenegger, M., Di Stefano, G., Radanov, B.P., & Schnidrig, A. (1994). Presenting symptoms and signs after whiplash injury: The influence of accident mechanisms. *Neurology*, *44*, 688–693.

Swartzman, L.C., Teasell, R.W., Shapiro, A.P., & McDermid, A.J. (1996). The effect of litigation status on adjustment to whiplash injury. *Spine*, *21*, 53–58.

Taylor, A.E., Cox, C.A., & Mailis, A. (1996). Persistent neuropsychological deficits following whiplash: Evidence for chronic mild traumatic brain injury? *Archives of Physical Medicine and Rehabilitation*, *77*, 529–535.

Voyvodic, F., Dolinis, J., Moore, V.M., Ryan, G.A., Slavotinek, J.P., Whyte, A.M., Hoile, R.D., & Taylor, G.W. (1997). MRI of car occupants with whiplash injury. *Neuroradiology*, *39*, 35–40.

Wallis, B.J., Lord, S.M., Barnsley, L., & Bogduk, N. (1996). Pain and psychologic symptoms of Australian patients with whiplash. *Spine*, *21*, 804–810.

Wechsler, D. (1945). A standardized memory scale for clinical use. *Journal of Psychology*, *19*, 87–95.

Wechsler, D. (1955). *Wechsler Adult Intelligence Scale manual*. New York: The Psychological Corporation.

Wechsler, D. (1987). *Wechsler Memory Scale–Revised manual*. San Antonio, TX: The Psychological Corporation.

Yarnell, P.R. & Rossie, G.V. (1988). Minor whiplash head injury with major debilitation. *Brain Injury*, *2*, 255–258.

Yoganandan, N., Pintar, F.A., & Kleinberger, M. (1999). Whiplash injury: Biomechanical experimentation. *Spine*, *24*, 83–85.