TWO PROCEDURES, ONE MECHANISM? RECENT FINDINGS ON THE AUTOMATION OF VOLUNTARY MOVEMENTS

by

KLAUS BLISCHKE[*]

Acquiring automaticity in voluntary movement production is usually thought of as a gradual shift in motor control from declarative to non-declarative memory structures, requiring extensive practice. Interference with a cognitive demanding secondary task should be high at the beginning of skill acquisition, but low once the automatic stage has been reached. Following this line of reasoning, three experiments were carried out. After a short initial learning phase, a criterion movement was practiced, along with provision of KR, either in a single-task condition (Exp.1, 1600 trials; Exp.2, 3200 trials), or in a dual-task condition (Exp.3, 560 trials). Performance was tested prior to and after practice. Tests included both a single- and a dual-task condition, with no KR provided. In the dual-task condition, an additional choice reaction time task had to be carried out concurrently to the criterion movement. Exp.1 shows clear evidence for dual-task interference in practice and control subjects, but no reduction of dual-task costs in the course of practice. In Exp.2, only at the very end of (single task) practice (i.e. after about 3000 trials), dual-task costs are completely reduced. Dual-task costs were also nearly eliminated in Exp.3, surprisingly after no more than 240 practice trials, when practice was carried out under dual-task conditions. Thus, there might be no gradual shift from the attentional to non-attentional control. Rather, two systems (attentional resp. non-attentional) seem to be working independently from each other.

Key words: kinesiology, movement co-ordination

Introduction

Acquiring automaticity in voluntary movement production generally is associated with stabilizing peak performance, and at the same time reducing

---

[*] Sportwissenschaftliches Institut der Universität des Saarlandes Saarbrücken, Dr. phil. Klaus Blischke Universität des Saarlandes Sportwissenschaftliches Institut, Geb. 39.3 Postfach 15 11 50 D-66041 Saarbrücken DEUTSCHLAND e-mail: k.blischke@rz.uni-sb.de

attentional control demands. Automatic performance should be fairly stable even under cognitive perturbation. Accordingly, automation can be operationalized as a reduction of performance-deteriorating interference in dual-task conditions. However, by what internal mechanisms automatic control can be achieved, is still open to discussion. During the recent years, various theoretical concepts have been proposed, differing considerably in their basic assumptions and in explanatory range. Unfortunately, their has been little effort so far in submitting these concepts to empirical scrutiny, especially with respect to the automation of movements (cf. Daugs, 1994; Blischke et al., 1996). Two such concepts that have been systematically evaluated in our laboratory shall be addressed here, namely "proceduralization", and "task-integrated operating mode".

"Proceduralization" conceptualizes a gradual shift from declarative to non-declarative mechanisms of movement control. An algorithmic problem-solving strategy, cognitively supervised at the beginning, will eventually be replaced by a stereotyped problem-solving procedure. This process is thought to involve a simplification of the internal control structure in one way or the other. Once proceduralized, the respective skill in its thus specific form won't require any attentional control anymore, because none-declarative mechanisms are supposed to operate in a non-attentional manner. Therefore, a successfully proceduralized skill should remain unaffected when different cognitively demanding secondary tasks are applied (at least as long as structural interference is precluded). Extensive practice of only that one skill in question is thought to be sufficient for achieving automaticity. Concepts of this kind have been advocated, e.g., by McKay (1982; 1985), and by Anderson (1987; 1992), the theory of the latter one having repeatedly been extended to motor tasks, too (e.g. by Masson, 1990).

Explicitly querying the idea of automaticity as related to the concept of proceduralization, an alternative view has been proposed by Manzey (1988; 1993), namely the "task-integrated operating mode". By this he meant skillful switching back and forth between two lines of action. One precondition to this is functional de-coupling of both tasks, which still have to be understood as being separate. A second prerequisite is the acquisition and consolidation of appropriate grouping strategies. To achieve this, according to Manzey's findings, *simultaneous* practice of both tasks is thought to be imperative.

To test the assumed practice effects of these two concepts, three experiments were conducted. In line with the general theoretical background outlined above, each experiment incorporated a dual-task paradigm.

Methods

Subjects: Eleven subjects took part in Exp.1, seven in the practice group, and four in the control group, that did not practice, but took part in the test runs according to the same schedule as the practice group. Four Ss took part in Exp.2, and another four in Exp.3. All Ss were adult and active athletes. Male and female Ss were balanced to the group conditions in Exp.1 and Exp.2.

Primary task: For a primary task a bipedal counter movement jump was chosen. Ss had to vertically displace their center of gravity for precisely 60 % of their individual maximum elevation height. Performance was assessed by means of a computer based biomechanical feedback system incorporating a KISTLER force plate. Terminal feedback in terms of the actual elevation height was available no later than five seconds after take-off from the platform, and during practice sessions usually was provided to Ss orally five to ten seconds after landing again at a reduced feedback frequency (i.e. after every fourth trial). There was no KR during performance tests.

Secondary task: As a secondary task, in the dual-task condition a *probe-reaction task* was used. In Exp.1 and Exp.2, this was a *choice-reaction*. Ss had to lift their thumb according to an ipsilateral tone signal transmitted via earphone. In *Exp.1*, on each trial Ss had to react on one out of four different times: either prior to, at the start of, in the middle of, or at the end of the jumping movement. All signals but the first one were triggered by defined features in the vertical ground reaction force-time course. Times were chosen in a pseudo-random fashion during each block of 20 test-trials, with four catch trials included. *Exp.2* incorporated *two probe-reaction dual-task variants*: Ss in a pseudo-random fashion again had to react *(a)* to the first or to the last tone signal in the one version, and *(b)* to the second or to the last signal in the other (choice-reaction in either case). There were no catch trials provided this time.

Altogether, dual task requirements in Exp.1 and in Exp.2 were pretty much alike. However, at the end of practice in Exp.2 (i.e. test5), all Ss in this study were confronted with *four different dual-task sets*, defined by the following secondary tasks to be carried out concurrently to the criterion movement: *(a)* the *standard* probe-reaction task variant Ss had encountered in their previous tests, *(b)* a *switch* to the *alternative* probe-reaction task so far presented to the other half of Ss, *(c)* a *calculation* task to be carried out concurrently to each block of 20 jumping trials, *(d)* the same calculation task in *combination* with the standard probe-reaction task of that group. Thus in test5, after extensive practice, Ss were exposed to systematic *changes of the dual-task context*. In the *first* part of *Exp.3,* during each block of trials Ss had to carry out a *single* reaction always at the same time relative to the jumping movement, catch trials provided again. Locus of time was known to Ss in advance (*fixed* dual-task condition). In the *second* part of this experiment, during each block of trials Ss had to accomplish *choice*-reactions again on all four randomly selected tone signals (*random* dual-task condition). Thus, in the first part of this study, the action-context could be fully anticipated, but not so in its second part.

Practice schedules: At the beginning of each experiment, Ss went through 20 acquisition trials augmented with KR (i.e. Knowledge of Results). This initial acquisition phase then was followed by different treatment conditions in each experiment. In the first two experiments, the primary task was practiced in *isolation*. In Exp.3, however, the same primary task was always practiced simultaneously to the respective secondary task. Practice amounted *(a)* to 1600 trials in Exp.1, completed within one week, *(b)* to 3200 trials in Exp.2, carried out over a three weeks period, and *(c)* to no more than 560 trials in Exp.3, 240 trials in the fixed dual-task condition, and another 320 trials in the random dual-task condition, all carried out within about half a week. Practice always proceeded in blocks of 20 trials, with KR provided every fourth trial.

Performance tests: Performance tests always included a *single*-task condition (STC), and a *dual*-task condition (DTC), either one without any KR. In *Exp.1*, three tests were applied during the practice phase, i.e. one prior to practice (test1), one after 800 practice-trials (test2), and one at the end of practice (test3) Retention tests followed three days (test4) and one week (test5) after practice had ceased. Each test required 120 trials per subject, 20 STC, and

100 DTC. In *Exp.2*, Ss underwent five tests from the start (test1) to the end of practice (test5), i.e. one every 800 practice trials, with each test amounting to 80 trials, 40 STC, and 40 DTC. Here, a retention test (test6) followed four weeks after the end of practice. In *Exp.3* again three tests were administered, one prior to practice (test1), one after 240 practice trials in the fixed dual-task condition (test2), and the last after another 320 practice trials in the random dual-task condition (test3). Each test amounted to 120 trials again, 40 SCT, and 80 DCT. In test2 in this study, Ss for the first time encountered the random dual-task condition. In all three experiments, performance tests covering the practice stage always were administered the next day after the resp. last block of practice.

Dependent variables: The dependent variable with respect to the *primary task* referred to here is *Absolute Error (AE)* with respect to the Ss' individual target elevation height. Also, Constant Error (CE) and a measure of variability were assessed. With respect to the *secondary* task, reaction times were assessed in DTC as well as in a choice- or single-reaction baseline condition on each test. Thus, in a specific test, higher error scores (AE), and longer reaction times in the DTC relative to the STC or the baseline-condition according to the dual-task paradigm indicate a need of attentional control for planning, initiating and execution of the criterion movement still being prevalent at that certain stage of practice.

Statistical analysis: For each dependent variable, data of all Ss in one cell (as defined e.g. by the factors TREATMENT, TEST, and TASK CONDITION) were pooled, and then subjected to statistical analysis. This made up for a fairly large amount of counts per cell and allowed for application of ANOVA-techniques and t-tests. It was made sure though by detailed data inspection, that all Ss belonging to one cell (or treatment condition) followed one and the same trend with respect to the crucial results.

Results and Discussion

In order to keep within the limited scope of this paper, only data of the primary task, i.e. the counter movement jump, will be presented here in some (statistical) detail, thus confining discussion to the very central aspects of this peace of research. The main results pertaining to the secondary probe-reaction task will be mentioned in the following section only very briefly. What is referred to here are always choice-reaction data produced in reacting to one out of the two *early* trigger signals (*prior* to resp. at the *start* of the jumping movement).$^{1)}$

In ***Exp.1***, AE is considerably higher in the DTC than in the STC. This goes for the practice group as well as for the control Ss. While treatment- and control-Ss do not differ statistically in test1, performance improves with practice, and decreases without. However, no reduction of dual-task costs is to be found (cf. Table 1).

Table 1. Absolute Error [cm] of primary task in Exp.1 ($\overline{x}$ = mean, s = standard deviation, n = number of cases). Data of practice group (7 Ss) resp. control group (4 Ss; no practice) are pooled over subjects in each test and task condition (STC = single-task condition; DTC = dual-task condition). Test1 was conducted 24 h after initial acquisition (20 trials) and preceded the practice interval. Test3 was conducted 24 h after practice was completed, or after the resp. time span had elapsed (for the controls). Test4 (2 days later) and test5 (1 week later) are long-term retention tests.

Treatment	**Task-Condition**		**Test**				
			1	**2**	**3**	**4**	**5**
Practice	**STC**	$\overline{x}$	2,34	1,20	1,17	1,39	1,11
		s	2,28	1,19	0,91	0,96	0,88
		n	118	128	139	157	160
	DTC	$\overline{x}$	2,34	1,44	1,49	1,63	1,66
		s	1,69	1,40	1,04	1,16	1,09
		n	698	698	679	696	700
Control	**STC**	$\overline{x}$	2,47	3,64	3,16	3,14	2,61
		s	1,89	3,19	2,54	2,62	2,79
		n	93	100	100	79	80
	DTC	$\overline{x}$	4,05	4,87	3,84	3,30	2,99
		s	2,91	3,91	2,70	2,86	2,89
		n	385	400	400	397	398

This is confirmed by a three-way ANOVA, conducted on the factors TREATMENT$_{\text{[TG; CG]}}$, TEST$_{\text{[test1; test3]}}$, and TASK CONDITION$_{\text{[STC; DTC]}}$, with significant results for all the three main effects ($F_{[\text{TREATMENT}]} = 508.937$, $F_{[\text{TEST}]} = 51.727$, $F_{[\text{TASK CONDITION}]} = 32.471$, with $p < .0005$ and df = 1/2604 in either case), and most of the interactions ($F_{[\text{TREATMENT X TEST}]} = 27.035$, $p < .005$, df = 1/2604; $F_{[\text{TREATMENT X TASK CONDITION}]} = 19.542$, $p < .005$, df = 1/2604; $F_{[\text{TREATMENT X Teast X TASK CONDITION}]} = 8.464$, $p = .004$, df = 1/2604), with only one interaction not reaching level of significance ($F_{[\text{TEST X TASK CONDITION}]} = 764$, $p = .382$, df = 1/2604). The significant two-way interactions are ordinal, the three-way interaction is hybrid. This means, AE is generally higher indeed in the DTC than in the STC even at the statistical level ($\varepsilon_{[\text{Task Condition}]} = .112$). At the same time, during the practice-period performance improves in the practice group as compared to the control group ($\varepsilon_{[\text{Treatment X Test}]} = .100$). And although performance improves, in test3 (different from test1) even in the practice group performance deterioration caused by dual-task requirements is found at a statistical relevant level, as is shown by the significant three-way interaction. As can be inferred from the control group data, test repetition per se neither causes learning, nor leads to any systematic reduction of dual-task costs.

In both groups, choice reaction times in the DTC at the beginning (in test1) are significantly longer than the resp. baseline values. In the practice group, dual-task reaction times in the course of practice nearly reach baseline values (test3), but become longer again during the retention period. In the control group, after some initial improvement (from test1 to test2), dual-task reaction times level off at constantly high values significantly above baseline values.

Exp.2 is characterized by isolated practice of the primary task and two different variants of dual-task test conditions. Two sub-groups (two Ss each) were assigned to each variant throughout test1 to test5. However, dependent measures in these two sub-groups being confronted with slightly differing dual-task variants do not differ in any respect at any point of time. Both data sets therefore are combined and then submitted to further statistical analysis. As performance data show, in Exp.2 AE again is higher in the DTC than in the STC at the beginning, but after 3200 practice trials and a considerable improvement in performance, dual-task costs now have completely vanished (cf. Table 2).

Table 2. Absolute Error [cm] of primary task in Exp.2 ($\bar{x}$ = mean, s = standard deviation, n = number of cases). Data of total practice group (4 Ss) are pooled over subjects in each test and task condition (STC = single-task condition; DTC = dual-task condition). Test1 was conducted 24 h after initial acquisition (20 trials), and preceded practice. Test5 was conducted 24 h after practice was completed. Test6 (4 weeks later) is a long-term retention test.

Treatment	**Task-Condition**		**Test**					
			1	**2**	**3**	**4**	**5**	**6**
Practice	**STC**	$\bar{x}$	1,85	1,04	1,04	0,81	0,96	0,78
		s	1,27	0,83	0,84	0,66	0,88	0,70
		n	157	160	160	160	160	160
	DTC	$\bar{x}$	2,25	1,29	1,11	1,29	0,84	0,79
		s	1,46	1,27	0,89	1,02	0,71	0,73
		n	157	160	160	160	160	160

This is confirmed by statistical analysis by means of a two-way ANOVA on the factors TEST$_{[\text{test1; test5}]}$, and TASK CONDITION$_{[\text{STC; DTC}]}$, with the (hybrid) interaction ($F_{[\text{TEST X TASK CONDITION}]}$ = 8.561, p = .004, df = 1/630; ε = 117), and the main-effect TEST ($F_{[\text{TEST}]}$ = 165.907, $p < .0005$, df = 1/630; ε = 513) both being significant. As is confirmed by t-tests, in test1 dual-task performance is significantly worse than single-task performance (t = -2.60, $p_{[\text{two-tailed}]}$ = .010, df = 306.39), while in test5 dual-task- and single-task-performance do not differ anymore statistically (t = 1.32, $p_{[\text{two-tailed}]}$ = .187, df = 318).

It should be stressed however, that dual-task interference does not disappear until during the very last 800 of 3200 practice trials. As further analysis reveals, Ss do not reach a performance-plateau in STC until in test4, i.e. after 2400 trials of practice. To this point, AE is still significantly higher in DTC than in STC. It is only from test4 to test5, that dual-task costs are utterly reduced. Again this is supported by the results of a respective two-way ANOVA (factors: TEST$_{[\text{test4; test5}]}$, TASK CONDITION$_{[\text{STC; DTC}]}$; results: $F_{[\text{TEST X TASK CONDITION}]}$ = 21.296, $p < .0005$, df = 1/636; $F_{[\text{TEST}]}$ = 5.000, p = .026, df = 1/636; $F_{[\text{TASK CONDITION}]}$ = 7.879, p = .005, df = 1/636).

Also, once the state of “automaticity”, according to our operational definition, has been reached, any *change* in the dual-task context remains without impact: Relative to single-task performance, none of the different dual-task sets in test5 does deteriorate performance at all (cf. Table 3).

Table 3. Absolute Error [cm] of primary task in the four different dual-task conditions of test5, Exp.2 ($\overline{x}$ = mean, s = standard deviation, n = number of cases). Data of total practice group (4 Ss) are pooled over subjects in each condition. Conditions are defined by the resp. dual-task sets, i.e. the set-specific secondary tasks: (a) ***Stand***ard-***P***robe***R***eaction***T***ask; (b) ***Switch***-***P***robe***R***eaction***T***ask; (c) ***Calc***ulation task; (d) ***Stand***ard-***P***robe***R***eaction***T***ask ***&*** ***Calc***ulation task. Test5 was conducted 24 h after practice was completed. Note that STC-performance in test5 amounts to an AE-score of 0.96 cm (cf. Table 2)!

Task-Condition		**Dual-Task Set**			
		Stand-PRT	**Switch-PRT**	**Calc**	**Stand-PRT&Calc**
DTC	$\overline{x}$	0,84	0,74	0,55	0,85
	s	0,71	0,68	0,57	0,86
	n	160	160	60	60

This is confirmed by an One-way-ANOVA conducted on the factor DUAL-TASK SET$_{[\text{Stand; Switch; Calc; Stand\&Calc}]}$. While the overall-result is significant (F = 2.899; p < .035; df = 3/436), Scheffé post-hoc-tests (α = 5%) reveal that there is no significant difference between any two of those four dual-task sets. So, at this point of isolated practice of the primary task, the combination of jumping movement and just the calculation task is less demanding than any of the other three dual-task sets.

From then on, performance in DTC and in STC remains stable during a long-term retention interval, as is confirmed by a two-way ANOVA conducted on the factors TEST$_{[\text{test5; test6}]}$ and TASK CONDITION$_{[\text{STC; DTC}]}$ with no significant results at all (F$_{[\text{TASK CONDITION}]}$ = .784, p = .376, df = 1/636; ; F$_{[\text{TEST}]}$ = 3.713, p = .054, df = 1/636; F$_{[\text{TEST X TASK CONDITION}]}$ = 1.196, p = .275, df = 1/636).

Dual-task reaction times in this experiment again (as already in Exp.1) are significantly longer than baseline values in the beginning (test.1), but after considerable improvement nearly reach baseline values in test4. From then on reaction times remain fairly constant even throughout the retention period.

In ***Exp.3***, in test1, Ss' AE in the anticipatory DTC does not differ statistically from that one in the STC. This finding, by the way, is well in line with the results of another study (Blischke, 1999), also incorporating the probe-reaction task in an anticipatory DTC. However, what really matters to us here is the transition from the anticipatory to the non-anticipatory context after no more than 240 practice trials, beginning with test2 (cf. Table 4). For in test2, Ss in this study for the first time encountered the random dual-task condition.

Table 4. Absolute Error [cm] of primary task in Exp.3 ($\bar{x}$ = mean, s = standard deviation, n = number of cases). Data of practice group (4 Ss) are pooled over subjects in each test and task condition (STC = single-task condition; DTC-Ant. = anticipatory dual-task condition; DTC-NonAnt. = none-anticipatory dual-task condition). Test1 followed 24 h after initial aquisition (20 trials) and preceded dual-task practice in an anticipatory condition. Test2 and test3 were conducted 24 h after dual-task practice in the anticipatory (test2), or in the non-anticipatory condition (test3) were completed.

Treatment	**Task-Condition**		**Test**		
			1	**2**	**3**
Dual-Task Practice	**STC**	$\bar{x}$	1,43	1,10	1,01
		s	1,06	0,98	0,99
		n	152	160	153
	DTC-Ant.	$\bar{x}$	1,65	▨	▨
		s	1,41		
		n	260		
	DTC-NonAnt	$\bar{x}$	▨	1,32	1,04
		s		1,01	0,99
		n		320	320

As a two-way ANOVA conducted on the factors TEST$_{[test2;\ test3]}$ and TASK CONDITION$_{[STC;\ DTC]}$ reveals, there are no dual-task costs any more in the *non*-anticipatory condition. Neither the main-effect TASK CONDITION (F = 3.541, p = .060, df = 1/949), nor the interaction (F = 1.744, p = .187, df = 1/949) do reach the level of significance. Only further improvement of performance in general can be stated ($F_{[TEST]}$ = 11.001, p = .001, df = 1/949).

Dual-task choice-reaction times in Exp.3 do not differ from the resp. baseline values any more beginning with test2.

Conclusions

While the dual-task costs in Exp.1 substantiate attentional workload of the criterion task, and rule out carry-over effects merely resulting from repeated testing, complete reduction of dual-task interference in Exp.2 and the robustness of this finding with respect to the introduction of various new secondary tasks seem to support the concept of proceduralization. That is, contrary to Manzey's statement, by *isolated* practice of some thousand trials motor skills *can* be transferred to a state of non-attentional control, which is independent of the type of secondary task applied, and remains stable for at least a month without any further practice. At the same time, however, the results of Exp.3 superficially seem to speak in favor of Manzey's notion of a task-integrated operating mode developed during simultaneous practice. Here, dual-task practice (in an anticipatory context) leads to near extinction of dual-task costs even when performance is tested in the same none-anticipatory dual-task context as in Exp.1 and in Exp.2. This finding was replicated just recently in an experiment including a control group. While in the treatment group (dual-task practice) of this replication study results were quite similar to Exp.3, the control-Ss showed marked increase in dual-task costs when transferred from an anticipatory to a non-anticipatory dual-task context (cf. Blischke, 1999).

Does this mean now, both concepts are to be sustained side by side? Some details in our findings seem to stand against such a conclusion. In Exp.3, when first introduced, the *non*-anticipatory dual-task condition did *not* raise dual-task costs to a statistical relevant level, although it had *not been practiced before*. This is at odds with Manzey's view, according to which any reduction of dual-task costs should be *confined to the task combination specifically practiced*, with *no transfer* to other task combinations. Therefore, the switch from the anticipatory to the none-anticipatory dual-task condition in Exp.3 should actually have *raised* AE considerably (as in fact was the case in the control condition of the above mentioned replication study). Also, there is this remarkable difference between Exp.2 and Exp3. in the amount of practice needed to reach the state of automaticity, which calls for further explanation.

Indeed an alternative line of reasoning that seems more appropriate to our experimental outcomes than the two concepts discussed so far, could be drawn from findings in the fields of implicit motor learning (Curran and Keele, 1993; Keele, Davidson and Hayes, 1998) and of brain-physiological PET-studies (Grafton, Hazeltine and Ivry, 1995): In motor learning, always two central nervous systems are involved, differing in function and anatomical basis. A "non-attentional" system allows for learning in an attention-distracting context, as e.g. in a dual-task context. From start on, this system's operating mode is automatic. An "attentional" system, on the other hand, is active only under but slightly distracting conditions. Both systems are working independently of each other. Movement control will be executed *either* by the attentional, *or* by the non-attentional system. There is no gradual shift from one system to the other.

A skill will be automatic then, when the non-attentional system has had the opportunity of controlling movement production *often enough* to handle that process effectively by itself. In a dual-task context this will, of course, be much sooner the case, than in the less distracting single-task context, where the attentional systems takes over control in most instances. So this hypothesis at the same time incorporates both concepts' predictions, and our otherwise incompatible results. And it can also explain for the huge difference in the number of practice trials needed to effectively reduce dual-task interference in the single-task type of practice (Exp.2) as compared to the dual-task type of practice (Epx.3). Rather than assuming various separate explanatory models for movement automation, our data support the notion of *one and the same mechanism* being active to a larger or to a lesser extent, depending on the chosen practice *procedure*.

Reference note

1) There are very robust differential effects depending on the time locus of the various tone signals, discriminating in between *early* and *late* trigger signals and reaction times pertaining to either one of these categories. This effect, according to a follow-up study, can be attributed at least to some extent to an

interaction of the ballistic leg movement (primary task) and the thumb movement (secondary task), specifically facilitating *late* reaction times (positive structural interference due to peripheral mechanisms; Blischke, in prep). Therefore, reaction time data pertaining to the late trigger signals are not debated in this paper. However, the *early* triggered reactions are *not* affected by this mechanism, and therefore can be judged as valid indicators of cognitive (attentional) workload.

REFERENCES

Anderson J.R. 1987. Skill acquisition: Compilation of weak method problem solutions. Psychological Review, 94, 192-210.

Anderson J.R. 1992. Automaticity and the ACT* theory. American Journal of Psychology, 105, 165-180.

Blischke K. 1999. Befunde zur Bewegungsautomatisierung. In K. Roth, T. Pauer, and K. Reischle (eds.), Dimensionen und Visionen des Sports, Hamburg: Czwalina, 89.

Blischke K. (in prep.). Studien zur Bewegungsautomatisierung

Blischke K., Daugs R., Reiser M., & Panzer S. 1996. Informationeller Aufwand und extensives Üben: Eine Pilotstudie zur Bewegungsautomatisierung. psychologie und sport, 3, 54-68 (in German, English summary).

Curran T., & Keele S.W. 1993. Attentional and nonattentional forms of sequence learning. Journal of Experimental Psychology: Learning, Memory, and Cognition,19, 189-202.

Daugs R. 1994. Zum Problem der Bewegungsautomatisierung: Der Einfluß extensiven Übens auf die menschliche Motorik. psychologie und sport, 1, 94-105 (in German, English summary).

Grafton S.T., Hazeltine E., & Ivry R. 1995. Functional mapping of sequence learning in normal humans. Journal of Cognitive Neuroscience, 7, 497-510.

Keele S.W., Davidson M., & Hayes A. 1998. Sequential representation and the neural basis of motor skills. In J.P. Piek (ed.), Motor behavior and human skill. Champaign, Il.: Human Kinetics, 3-28.

Manzey D. 1988. Determinanten der Aufgabeninterferenz bei Doppeltätigkeiten und ressourcentheoretische Modellvorstellungen in der Kognitiven Psychologie. Hamburg: DFVLR.

Manzey D. 1993. Doppelaufgabeninterferenz: Neue theoretische und methodische Perspektiven für ein altes Paradigma. In R. Daugs & K. Blischke (eds.), Aufmerksamkeit und Automatisierung in der Sportmotorik. Sankt Augustin: Academia, 79-96.

Masson M.E.J. 1990. Cognitive theories of skill acquisition. Human Movement Science, 9, 221-239.

McKay D.G. 1982. The problem of flexibility and fluency in skilled behavior. Psychological Review, 89, 483-508.

McKay D.G. 1985. A theory of representation, organisation and timing of action with implications to sequencing disorder. In E. Roy (ed.), Neuropsychological studies of apraxia and related disorders. New York: