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ORIGINAL INVESTIGATION

Differential effects of single versus combined cognitive and physical training with older adults: the SimA study in a 5-year perspective

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Abstract The present study evaluates the effect of cognitive training, of psychoeducational training and of physical training on cognitive functioning, physical functioning, physical health, independent living and well-being in older people. Also the combination of physical training with cognitive training or psychoeducational training, respectively, was evaluated. In contrast to most training studies with older people, training effects were evaluated in a longitudinal perspective over 5 years to analyse long-term-results of cognitive and physical activity on older adults. Training effects were evaluated compared to a no-treatment-control group. Subjects were 375 community residents aged 75–93 years. Up to 5 years after baseline examination, significant training effects were observed in the group exposed to the combined cognitive and physical training. The physical and cognitive status in the participants of this group could be preserved on a higher level compared to baseline, and the participants displayed fewer depressive symptoms than the no-treatment-control group. The results are discussed in the light of recent research regarding the effects of mental and physical activity on brain function in older adults.

Keywords Cognitive training · Physical training · Independent living · Dementia

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Introduction

In view of the increasing proportion of old people in societies around the globe, the question of how and to what extent the loss of independent living of older adults may be prevented is gaining in importance. Following Verbrugge (1990), three classes of disability can be differentiated that contribute to a significant loss of independence: mental (i.e. cognitive abilities and emotional states), physical (i.e. basic actions required for daily living, such as mobility, balance, strength, endurance), and social which is preceded by physical and mental functions. Up to now, there is a great number of experimental studies that evaluated the effects of physical training and of cognitive training, respectively, on physical functions, cognitive functions, and mental status in older people.

With respect to physical functioning, a meta-analysis of experimental studies by Spirduso and Cronin (2001) shows that long-term physical activity is related to postponed disability and independent living in the oldest-old subjects. Even in individuals with chronic disease, physical function may be improved by physical activities. A review of training studies of Carlson et al. (1999) found that exercise has been shown to improve strength, endurance, flexibility, and balance in older adults. In a randomized, controlled study of Sihvonen et al. (2004) it was proved that even in frail older women a balance training program improved balance control regarding tasks relevant to daily living. In the Longitudinal Aging Study Amsterdam, an observational study, Visser et al. (2002) found that physical activity and a regular active lifestyle (e.g. walking outdoors, bicycling, household activities, sports activities) are associated with a smaller decline in physical functioning and may slow this decline. Carlson et al. (1999) conclude in their review of training studies, that physical activity even might reverse physical disabilities. Furthermore, a meta-analysis on intervention studies by Netz et al. (2005) revealed that there are also positive effects of physical activity on emotional well-being in older adults. So it appears that sustained exercise is a highly effective form of prevention of disability.

With respect to cognitive performance, a large number of experimental training studies has found concordant evidence for high levels of developmental potential and plasticity of cognitive functions (e.g. Blieszner et al. 1981; Schaie and Willis 1986; Stigsdotter and Bäckman 1995; Willis and Nesselroade 1990). In a meta-analysis of experimental studies this result was confirmed (Kramer and Willis 2003). As theoretically age-related slow-down of information processing speed is considered as a major factor of cognitive aging, training approaches to improve cognitive speed are most relevant. Controlled experimental studies proved that information processing speed can effectively be improved by regular training (Edwards et al. 2005). Following a training of cognitive speed, Edwards et al. (2005) found intervention effects on tasks that simulated instrumental activities of daily living (Timed IADL; Owsley et al. 2002). However, it was not analyzed whether there are long-term effects of such training. Effects of training on inductive reasoning, for example, lasted up to 7 years in the Seattle Longitudinal Study (Schaie and Willis 1986; Saczynski et al. 2002). Memory functions may be improved by a training of specific memory strategies (e.g. verbal categorization, elaboration, visual imaging) (Yesavage 1985; Cavallini et al. 2003).

Recently in the ACTIVE-study (Jobe et al. 2001; Ball et al. 2002), a randomized, controlled trial of cognitive training, intervention effects were focused on cognitively demanding everyday functioning (e.g. financial management). Furthermore, training effects were measured regarding everyday problem solving, everyday speed and (instrumental) activities of daily living. The first results of this study revealed that after cognitive training (memory training, reasoning training, speed-of-processing training) the participants performed better on measures of the cognitive abilities for which they were trained. These training effects continued through 24 months. The effects of cognitive training may be of an amount that equals the amount of the age-related decline (Ball et al. 2002).

However, there were no training effects on everyday functioning at 2 years follow-up (Ball et al. 2002). This may be due to the fact that there was low decline in everyday functioning in all persons, including the control group. As Ball et al. (2002) suppose, possibly training effects on everyday-functioning may not be detected before there is a greater amount of functional loss with progressing age. Therefore a longer follow-up-period would be necessary to reveal training effects on independence, as everyday abilities decline later than cognitive functions (Edwards et al. 2005).

The negative effect of an impaired emotional status on independence may also be reduced by cognitive training, as memory and problem-solving abilities are important mediators in the relationship of depressive symptoms and functional disability (Gallo et al. 2003).

Empirical data indicate that there is a positive relationship between mental and physical activity and the functional capacity of the brain cells. Early experimental studies regarding the effects of physical exercise on neuropsychological function in older persons (Diesfeldt and Diesfeldt-Groenendijk 1977; Molloy et al. 1988) and recent meta-analyses of experimental studies (Colcombe and Kramer 2003; Heyn et al. 2004) revealed, that physical activity not only increases strength, physical fitness and functional performance, but also results in improvements in cognitive functions. Various findings of neurophysiological research suggest that mental and physical activities enhance synaptic connections between the brain cells and neuronal plasticity (Bennett et al. 1996; Spatz 1996), i.e. trigger the formation of additional connections between the brain cells and perhaps even the creation of new brain cells (Eriksson et al. 1998). Therefore, the combination of mental and physical training programs seems to be of particular value for synaptic plasticity and potential neurogenesis (Kempermann et al. 1997).

However, as specific training effects of cognitive training and physical training, respectively, on cognitive functions and physical functions and on emotional status are well documented, there are nearly no well-controlled experimental studies that have found evidence for long-term effects of cognitive training or physical training on everyday activities. The long-term effects detected thus far have been found in tasks that are very similar to the training activities (Stigsdotter and Bäckman 1995; Willis and Nesselroade 1990; Kramer and Willis 2002; Ball et al. 2002; Edwards et al. 2005). Other studies have failed to observe maintenance effects at the long-term follow-up (Anschutz et al. 1987; Scogin and Bienias 1988). Furthermore, so far there is no empirical research regarding the effect of a combined training on physical and cognitive functions, on mental status or on independence.

The present controlled study was designed to analyze long-term-effects of cognitive and physical training on behalf of improving not only cognitive and physical functions, but also physical health, independent living and emotional well-being in persons of 75 years of age and older. Beyond cognitive and physical training, a cognitive oriented, psychoeducational training approach was developed that aimed directly to problem solving strategies related to demands of everyday life.

Furthermore, a new training approach was introduced by combining cognitive and psychoeducational training, respectively, with physical training. This approach is theoretically based on the above mentioned empirical results regarding the beneficial effects of physical activity on cognitive function. So each training approach was implemented as a "single training" (cognitive training, psychoeducational training, physical training) or as a combined training of cognitive and physical training or psychoeducational and physical training. Effects were controlled by a no-treatment-control group.

Training effects were evaluated in a long-term-perspective over 5 years, because an age-related decline of cognitive and physical functions in adults aged 75 years or older is to be expected in this period. Thus it is possible to evaluate whether the training counteracts age-related decline compared to a control group without training.

Methods

Sample

Participants were recruited through publishing articles on the project in local newspapers, through taking up contact with members of senior clubs, social services and charitable institutions involved with senior citizens and through giving public presentations on the project. So the sample consisted completely of volunteers. A total of 708 persons were interested in the project. These interested elders were informed about the project in detail by written material and screened by a short self-administered questionnaire to check for exclusion criteria. The screening included questions for birth date, health status, sensory impairments and the readiness to take part in regular training sessions. Persons were exluded from the study

- if they were younger than 75 years, did not live independently and had already experienced functional cognitive or physical decline or suffered from medical conditions that hindered to take part regularly in at least one of the training approaches,
- if they reported substantial self-reported hearing or visual loss that would make participation in the training impossible,
- if they were not able to visit the training sessions regularly.

Five hundred and ninety-five screening questionnaires were returned. Of the 595 individuals who sent back the questionnaire, 66 were younger than 75 years of age and 42 lived in institutions and therefore were excluded from the sample, 98 refused to participate in the pretests and 14 persons claimed that after having received detailed information on the project, they were no longer interested in participating. The study began in 1991 with a total of 375 participants (64.8% women) aged 75–93 years. The mean age at baseline was 79.5 (±3.5) years. Sample characteristics can be found in Table 1.

Comparing the demographic characteristics of participants with those of a random sample representative of the same age group in the region of Nuremberg-

Table 1 Sample characteristics

	Study sample	
	Abs.	Percentage (%)
Age (Years)		
75–79	221	58.9
80–84	118	31.5
85–89	33	8.8
90–94	3	0.8
Sex		
Female	243	64.8
Male	132	35.2
Marital status		
Single	30	8.0
Married	108	28.8
Widowed	215	57.3
Divorced	22	5.9
Level of education		
Without graduation	0	0.0
Primary school	154	41.1
Secondary school	147	39.2
Abitur[a]	54	14.4
University graduation	20	5.3
Vocational qualification		
Unskilled	34	9.1
Worker	131	34.9
Employee	118	31.4
Entrepreneur	22	5.9
House-wife	70	18.7
Income per month		
<250€	4	1.1
250–500 €	9	2.4
500–1,000€	122	32.5
1,000–1,500€	131	34.9
1,500–2,000€	70	18.7
2,000–2,500€	28	7.5
>2,500€	11	2.9

[a] German school leaving examination and university entrance qualification

Fuerth-Erlangen in Germany where the study was carried out, no significant differences were found with respect to gender, marital status, schooling, vocational qualifications, or income. Overall, the results confirm that the sample is typical of voluntary study populations for the age range considered. Nevertheless, a sample bias may not be excluded because also randomly drawn participants take part voluntarily, and it may be that older persons who decide to take part in a study differ from those who do not take part.

Interventions

Cognitive training

The cognitive training (Oswald 1998) aims at fluid abilities (information processing speed), attention and memory functions. The training of speed of information and attention was focused on visual search tasks. Visual information (e.g. a specific number or letter) was to be located as quickly as possible (e.g. in a row or a diagram of numbers or letters). Another task for speed of information training was a modified form of a geriatric version of the maze test and the word-colour-test (Oswald and Fleischmann 2006).

Memory training included training of short-term storage and retrieval of verbal, visual or numerical material, as well as the training of memory strategies for long-term storage like verbal categorization, verbal elaboration or visual imaging for remembering names and numbers or more complex information of texts. The memory tasks were mainly related to demands of daily life (e.g. telephone numbers, names, shopping lists, newspaper texts). Furthermore, the participants received information on ageing processes of memory functions and were provided with strategies to compensate for age-related decline in memory functions (e.g. using memory lists). The participants were encouraged to train at home and received handouts and written exercises.

Physical training

The physical training (Baumann and Leye 1995) included predominantly the training of balance, perceptual and motor coordination and flexibility. Furthermore, the program aims to increase the participants' overall level of activity by involving them in a variety of gymnastic exercises and games. In the first part of the training, a very broad holistic physical activation was to be obtained in the subjects by offering training of different movements (e.g. gymnastics, dancing, simple structured game skills). In the second part, a learning program was employed, e.g. family tennis or table tennis skills. The coordination of movement under time pressure could be practiced here, since each movement had to be performed on a speed schedule. In the third part, the learning program was intensified through exercising skills taken from games, dancing and yoga.

Psychoeducational training

A cognitive demanding, everyday-oriented psychoeducational training (Oswald and Gunzelmann 2001) was developed as an alternative approach to the cognitive training. It was supposed that the age-related decline of physical and cognitive functions and changes in social relations (e.g. loss of spouse) would make coping with daily demands more difficult. Therefore the training aimed to strengthen individual resources to cope with every day life demands. The training focused on a wide range of prototypical demands or problems, e.g. changing physiological functions and related demands for nutrition in old age, technical aids in the household to compensate for decreasing physical strength, falls prevention at home by age-adequate furnished apartments, medication intake and understanding of prescribtion labels, coping with loss of social contacts and with decreasing health or problem solving in every day life. Information was given on the availability of and access to technical and financial aid for ill or disabled people and on health care services for senior citizens (e.g. a guide to the regional services for older people was developed). The training included lectures, group discussions, exercises, role plays (e.g. social skills, problem solving), handouts and check-lists.

Implementation of training interventions

Participants of each training approach were assigned to small training groups of about 15–20 members each. The training took place every week over 30 sessions. Groups were conducted by two trained group leaders each who used standardised written training manuals. Cognitive training and psychoeducational training lasted 90 min each session, physical training lasted 45 min each session. In the combined training, in each session there were 90 min of cognitive or psychoeducational training, respectively. Physical training was carried out in the same session for further 45 min. Because it was not clear whether there is an effect of the order of the training approaches in the combined training, physical training was carried out before cognitive or psychoeducational training in a part of the training groups and following cognitive or psychoeducational training in another part of the groups. Thus a possible effect of the order of training approaches should be levelled out. To ensure, that the participants of each training approach received an equal amount of social contact, there were additional unspecific social activities in the training approaches with cognitive training, psychoeducational training or physical training alone.

Due to organizational reasons it was not possible to completely assign the participants randomly to the treatment methods (cf. Table 2). Rather, some exceptions of randomization were necessary. If participants were not able to take part in the physical training due to limited physical fitness or health complaints that restricted physical activity (e.g. heart diseases), they were not assigned to physical training. Spouses could not be assigned to different groups, because in this case they would have refused to take part in the study. Because the training groups took place in two towns and at different locations in each town, participants could not be assigned randomly across all groups. Furthermore, because the two towns were not comparable regarding the number of older inhabitants, it was not possible to hold the number of training groups in each town equal. On the whole, these organizational restrictions resulted in different sample sizes between the training approaches. However, no differences were found between the groups regarding age, sex and the baseline values of the dependent variables (c.f. Baseline differences).

The initial examination in 1991 was followed by a training phase lasting approximately 1 year. Annual follow-up assessments were conducted from autumn 1992 until autumn 1996. Due to organizational conditions, assessors could not be held blind to participant intervention assignment.

Outcome measures

Following the conceptualisation of independent living by Verbrugge (1990), cognitive function and the emotional status (both representing mental state) as well as physical status are prerequisites for independent living. Interventions to preserve independent living, therefore, have to be evaluated on the basis of these functions (cf. Table 2).

The assessment of cognitive functions is based on an information processing model of cognition and thus includes measures of information processing speed, attention, primary and secondary memory, long term memory and reasoning. The test scores of the single measures (cf. Table 2) were transformed to *z*-scores and then summarized to a composite score defined as "cognitive function". Furthermore, cognitive impairment was rated by interviewers as an early indicator of dementia symptoms which are most relevant for the loss of independent living.

Emotional status was assessed regarding depressive mood because this is the most prevalent emotional disorder in the older adults (Baltes and Mayer 1999).

Physical functions are determined mainly by strength, endurance, coordination, flexibility, and balance (Carlson et al. 1999). These were operationalized by different psychomotor tests (cf. Table 2). As for cognitive function, the single measures were combined by transforming each value to *z*-scores and computing a composite score defined as "physical function".

"Physical function" was only assessed in participants of physical training, combined training (i.e. cognitive and psychoeducational training, respectively, with physical training) and in the control group. Because some special equipment and specialized personal is required for the assessment of physical functions, and physical functions could only be assessed during physical training, it was not possible to assess physical functions in all training groups due to personal and organizational limitations.

Beyond these domains which are considered as essential for independent living, independent living was also rated directly. Therefore, different criteria for independent living were defined. Even if there is no consensus regarding the construct of independent living (Wahl 1991), in general it is considered as a multidimensional construct that at least involves the ability to fulfil (instrumental) activities of daily living without the help from others. However, there may be ceiling effects with ADL- and IADL-scales in community-dwelling, healthy older people, so that possible training effects can not be detected (cf. Ball et al. 2002). Therefore, in the present study, independence was evaluated on the basis of a self-rating and on the basis of an expert rating (cf. Table 2). The participants were asked: "Imagine you would rate your independence on a scale from '0' to '100'. '100' means that you don't need any help in your daily living; '0' means that you need help in every daily activity (e.g. doing the buying, cooking, financial matter)". The interviewer rating was based on a qualitative interview regarding problems in daily life (e.g. getting help of others, realizing memory problems, limitations in leisure activities and social activities). Comparable to the self-rating, the interviewers rated independence on an analogous scale from "completely dependent" (i.e. needs help in every daily activity) to "completely independent" (i.e. does not need any help in daily activities). As a more objective indicator of independent living, the use of health services (e.g. "meals on wheels", nursing care at home

Table 2 Outcome measures

Domain (composites)	Variables	Psychometric tests or ratings
Cognitive function	Speed of information processing	Number connection test (NC-G), Maze test (MT-G), Digit symbol substitution test (DS-G) (Neuropsychological aging inventory NAI; Oswald and Fleischmann 2006)
	Attention	Alters-Konzentrations-Test (Aging concentration test, Gatterer 1990), Color word test (CWT-G) (Neuropsychological aging inventory NAI; Oswald and Fleischmann 2006)
	Primary memory	Memory span (MS-G), Sentence test (ST) (Neuropsychological aging inventory NAI; Oswald and Fleischmann 2006)
	Secondary memory	Picture test (PT), Figure test (FT), Word list (WL), Word pairs (WP) (Neuropsychological aging inventory NAI; Oswald and Fleischmann 2006)
	Long term memory	Information (WAIS-Info) (Wechsler adult intelligence scale, German version), Word fluency (Leistungsprüfsystem LPS, Horn 1983)
	Reasoning	Similarities (WAIS-Sim) (Wechsler adult intelligence scale, German version; Wechsler 1981)
Cognitive impairment		Interviewer rating (Sandoz clinical assessment geriatrics SCAG; Shader et al. 1974)
Physical function	Coordination	Modified KTK-test (physical coordination test)
	Flexibility (trunk and shoulder)	Bending forward and sideward, arm-lifting test
	Rhythm	Knocking test with coordination of leg and arm
	Adaptability	Table-tennis-accuracy-test
	Readjustment to a moving object	Table-tennis juggle test
	Agility/endurance	Walk/run through a course with different tasks
	Strength	Handgrip test
Emotional status	Depression	Self rating (Zung Self-Rating Depression Scale SDS; Zung 1965)
Independent living	Participant's self-rating of independent living	Rating on an analogue scale from "completely independent" to "completely dependent" regarding the question: "Imagine you would rate your independence on a scale from '0' to '100'. '100' means that you don't need any help in your daily living; '0' means that you need help in every daily activity (e.g. doing the buying, cooking, financial matter)".
	Interviewer rating of independent living	Rating on a analogue scale from "completely dependent" (0, i.e. needs help in every daily activity) to "completely independent" (100, i.e. doesn't need anly help in daily activities)
	Use of health-care services	Self-administered questionnaire regarding use of "meals on wheels", nursing care at home, other paid services
Everyday competence	Interviewer rating of the participant's coping with age-related problems	Rating based on interview questions
Health status	Objective health	Clinical assessment of organ functions (e.g. cardiovascular diseases, diseases of the respiratory system, diseases of the digestive tract, diseases of the joints, neurological symptoms, hearing loss, impaired vision, hand grip), laboratory tests (e.g. blood count, cholesterol level)
	Subjective health	Self-rating of perceived health
Well-being	Subjective aging	Self-rating questionnaire: neuropsychological symptom list NSL-S (Neuropsychological aging inventory NAI; Oswald and Fleischmann 2006), 20 items regarding subjective age-related problems and limitations in neuropsychological and everyday functions, e.g. experiencing reduced cognitive functions, loss of physical energy, loss of social contacts)
	Quality of life	Self-rating questionnaire: Neuropsychological assessment of life quality NLQ-S (Neuropsychological aging inventory NAI; Oswald and Fleischmann 2006)
	General well-being	Self-rating questionnaire: Neuropsychological assessment of subjective well-being NSW-S (Neuropsychological aging inventory NAI; Oswald and Fleischmann 2006)

and other paid aids) was considered as an indicator of the decline of independence. These measures (self-rating, interviewer-rating, use of health services) were each transformed to z-scores and then summarized to a composite measure defined as “independent living”.

Furthermore, the ability to cope with environmental demands and age-related decline in cognitive and physical functions was considered as a relevant aspect of independence (North and Ulatowska 1981; Verbrugge 1990). It was interviewer-rated, based on a qualitative interview (“If you feel that with growing age it gets more difficult to cope with some daily activities as doing the household, for example, what do you do to compensate for this? Did you take specific precautions if you get ill or in need of help in daily living with advancing age?”). This measure was defined as “everyday competence”. It was not included in the composite score of “independent living”, because it rather reflects individual strategies to preserve one’s independence, whereas “independent living” reflects rather the present status.

Health status was considered as a separate construct with high relevance for independent living, because multimorbidity may be considered as a risk factor for the loss of physical and cognitive functions and is related to depressive mood (Baltes and Mayer 1999). Therefore, an extensive medical assessment was carried out to measure physical disorders, chronic organic diseases and impairments of body functions and sensory functions. Because there is also a significant relation between activities of daily living and subjective health (Pinquart 2001), the medical assessment was completed by the participants’ self rating of their health status. All medical assessments and the subjective health rating were transformed to z-scores and summarized to a composite measure of “health status”.

Furthermore, effects of the training on well-being were evaluated, because this is generally considered as an important indicator of therapeutic effects in older people beyond functional criteria (von Steinbüchel et al. 2006). “Well-being” was defined as a composite measure of a self-rating of subjectively experienced age-related problems, a quality of life measure and a self-rating of general well-being (cf. Table 2).To build this composite score, the test sores were transformed to z-scores and then summed up.

Data analysis

The results presented are based on analyses with decreasing numbers of participants across the 1991–1996 period. Since the scales of the different parameters varied, a z-score transformation was based on taking the mean and standard deviation of all the initial scores of all participants (intervention groups and control group) for whom initial as well posttest-scores were available ($n = 309$). The z-score transformation of the posttest-scores was also based on the means and distributions of the respective initial score of each variable, so that all changes are presented in standard deviations of the initial scores of the total sample. The longitudinal differences between the control group and the treatment groups were tested separately for each treatment group using multivariate Wilcoxon–Mann–Whitney-tests (two-tailed) for the period of the study following Wei and Lachin (1984). With this non-parametric procedure it is possible to analyze differences in the longitudinal course of dependent variables between groups (analogous to a multivariate analysis of variance with repeated measures). The longitudinal analysis was based on the remaining number of participants in the respecting follow-up-year (cf. Table 3).

Parametric multivariate measures were not used because the statistical prerequisites were not given (normal distribution, homogenity of variances). According to the explorative character of the study, the results should be considered as descriptive (cf. Abt 1987). Effect sizes were computed following Hedges (1982, pp. 491–492).

Results

Baseline differences

Because results may be related to age or baseline values of the dependent variables, for instance, it was tested whether the groups were similar at baseline. There were no statistical differences regarding age

Table 3 Development of sample

Treatment	1991		1992		1996	
	N	%	*N*	%	*N*	%
Control group	103	100	97	94.2	53	51.5
Treatment group						
Psychoeducational training	115	100	85	73.9	47	40.9
Cognitive training	57	100	46	80.7	29	50.9
Physical training	32	100	29	90.6	15	46.9
Psychoeducational and physical training	36	100	28	77.8	18	50.0
Cognitive and physical training	32	100	24	75.0	17	53.1
Total	375	100.0	309	82.4	179	47.7

To ensure clarity of presentation, the values for 1993, 1994, and 1995 are not reported in this table

($P = 0.09$), sex ($P = 0.45$) and the dependent variables (“cognitive function”: $P = 0.29$; “cognitive impairment”: $P = 0.59$; “physical function”: $P = 0.16$; “emotional status”: $P = 0.19$; “independent living”: $P = 0.99$; “everyday competence”: $P = 0.24$; “health status”: $P = 0.68$). Only “well-being” was different between the groups [$P \leq 0.001$; c.f. Table 4 for detailed baseline values (standardized *z*-score) of the different groups].

Drop-out-analysis

During intervention time and follow-up (1991–1996) the number of participants dropped from an initial 375 (272 in treatment groups and 103 in no-treatment-control group) to 179 (126 in treatment group and 53 in no-treatment control group; cf. Table 3). Sample attrition was comparable across the different groups. The number of participants in the control group dropped from 103 to 53 (51.5%); in those given cognitive training, from 57 to 29 (50.9%), in the groups given psychoeducational training, participant numbers declined from 115 to 47 (40.9%); and in those given physical training, from 32 to 15 (53.1%). In the combined training approaches, the drop-out rates were 50.0 for psychoeducational and physical training and 46.9% for cognitive and physical training. Besides the self-selectivity bias at baseline, the sample displayed the attrition that is characteristic of longitudinal studies, with weaker and less healthy participants dropping out over the course of the study. Participants who dropped out were significantly older than participants ($P < 0.001$). However, there were no differences regarding drop-out rate between the groups ($P = 0.64$).

Post-treatment effects

One year after the start of the intervention at post-treatment, specific training effects resulted relative to the no-treatment-control group (cf. Table 4). Participants in the memory training experienced an improvement in “cognitive function”, and members of the combined psychoeducational and physical training improved in “independent living” and “everyday competence”. Physical training alone (i.e. not combined with cognitive training) did not bring about an improvement in the status of “physical function”. However, combined with cognitive training, there was an improvement in “physical function” and “independent living”. Even at this relatively early point in the study, the group exposed to combined memory and physical training evidenced the largest gains in “cognitive funtion”, “emotional status” and “physical function” relative to the control group. Effects on “well-being”, however, were attributable to baseline differences in the traning group’s favor.

Long-term training effects

In comparison to the no-treatment-control group, the “cognitive function” of participants given single cognitive training and—to an even greater extent—participants exposed to combined cognitive and physical training improved significantly across the 5-year study period (both $P < 0.001$). However, only the participants in the combined cognitive and physical training displayed a consistently enhanced cognitive performance of some 0.4 *z*-scores higher than that of the control group. The effect size was $d_+ = 0.75$. Training effects of this magnitude were not observed in any of the other treatment groups.

It emerged that symptoms of “cognitive impairment” were far less pronounced among the members of the combined cognitive and physical training than among the members of the no-treatment-control group across the study period ($P < 0.001$; 1996 $d_+ = 0.59$). Significant differences in symptoms of “cognitive impairment” relative to the no-treatment-control group were not observed in any of the other treatment groups.

Relative to the control group, participants in the combined cognitive and physical training showed a higher degree of “independent living”. For the combined psychoeducational and physical training, an analogous result was only found for a single measure of independence, i.e. they used less health care services ($P = 0.01$), but not for the composite measure of “independent living”. No significant long-term effects were detected in any of the single treatment groups.

Longitudinal analysis of “health status” showed no significant effects. However, there were significant effects on single measures regarding health aspects. On the long term, participants in the combined cognitive training and physical training (1996; $d_+ = 0.49$) and the combined psychoeducational training and physical training (1996; $d_+ = 0.22$) were much less likely than the control group to experience impairments in organ function (both $P = 0.001$). The members of the combined cognitive and physical training experienced the largest number of significant and sustained training gains. The combined cognitive and physical training ($P = 0.004$) and the combined psychoeducational and physical training ($P = 0.02$) were also the only interventions to give better subjective health ratings than the control group.

The results for the “emotional status” were analogous. Only participants exposed to combined cognitive and physical training displayed fewer symptoms of

Table 4 Results of the longitudinal analyses by treatment group (z-transformed means and standard deviation and pretest–posttest effect sizes (d_+)

Domain (composites) treatment	1991		1992			1996			Control vs. treatment (longitudinal effects[a] 1991–1996)
	M	SD	M	SD	d_+	M	SD	d_+	
Cognitive function									
Control	−0.01	0.50	0.03	0.49	0.06	0.07	0.46	0.15	
Psychoeducational	−0.15	0.62	0.07	0.55	0.38	0.03	0.66	0.29	*
Cognitive	0.00	0.60	0.52	0.49	0.95	0.21	0.62	0.35	***
Physical	−0.15	0.67	−0.15	0.71	−0.01	−0.40	0.77	−0.36	
Psychoeducat. + physical	−0.11	0.78	0.12	0.63	0.32	−0.05	0.68	0.08	*
Cognitive + physical	0.08	0.51	0.63	0.43	1.14	0.46	0.47	0.75	***
Cognitive impairment									
Control	−0.14	0.88	−0.22	1.03	−0.08	−0.46	1.57	−0.28	
Psychoeducational	0.01	0.88	−0.20	1.20	−0.20	−0.17	1.16	−0.19	
Cognitive	−0.08	0.76	0.00	0.95	0.09	−0.07	1.15	0.01	
Physical	0.00	1.00	0.01	1.06	0.01	−0.38	1.27	−0.35	
Psychoeducat. + physical	0.00	0.67	0.32	0.73	0.45	−0.11	0.92	−0.14	
Cognitive + physical	0.00	0.84	0.61	0.64	0.80	0.49	0.79	0.59	***
Physical function[b]									
Control	0.12	0.48	0.06	0.48	−0.13	−0.16	0.45	−0.59	
Psychoeducational	–	–	–	–	–	–	–	–	
Cognitive	–	–	–	–	–	–	–	–	
Physical	−0.13	0.55	−0.07	0.62	0.10	−0.30	0.52	−0.31	
Psychoeducat. + physical	−0.08	0.60	0.11	0.59	0.32	−0.19	0.93	−0.15	
Cognitive + physical	0.16	0.38	0.46	0.38	0.78	0.15	0.43	−0.01	*
Emotional status (depressive symptoms)									
Control	−0.05	1.02	0.03	1.06	0.08	−0.04	1.01	0.02	
Psychoeducational	−0.16	1.01	−0.04	1.08	0.12	−0.27	0.99	−0.11	
Cognitive	−0.08	0.96	0.15	0.88	0.24	0.15	0.88	0.24	
Physical	0.10	0.82	0.10	1.08	−0.01	−0.36	1.02	−0.53	
Psychoeducat. + physical	0.29	0.86	0.53	0.84	0.28	0.08	0.91	−0.24	
Cognitive + physical	0.03	0.92	0.45	0.89	0.47	0.25	0.74	0.26	*
Independent living									
Control	−0.06	0.74	0.13	0.78	0.24	−0.33	1.18	−0.30	
Psychoeducational	−0.02	0.68	−0.01	0.68	0.02	−0.29	1.10	−0.33	
Cognitive	0.11	0.71	0.13	0.67	0.03	−0.23	1.03	−0.41	
Physical	0.09	0.78	0.05	0.87	−0.04	−0.67	1.46	−0.72	
Psychoeducat. + physical	0.21	0.51	0.38	0.53	0.32	0.15	0.61	−0.11	*
Cognitive + physical	0.15	0.54	0.29	0.55	0.27	0.30	0.63	0.26	*
Everyday competence									
Control	−0.07	0.60	0.12	0.71	0.29	−0.03	0.67	0.07	
Psychoeducational	−0.11	0.60	0.33	0.51	0.77	−0.05	0.81	0.08	
Cognitive	0.05	0.64	0.20	0.63	0.23	−0.14	0.75	−0.28	
Physical	0.05	0.54	0.28	0.63	0.39	0.01	0.88	−0.05	
Psychoeducat. + physical	0.16	0.64	0.22	0.35	0.12	0.20	0.79	0.06	*
Cognitive + physical	0.12	0.50	0.28	0.62	0.30	0.02	0.71	−0.17	
Health status (objective and subjective health)									
Control	−0.05	0.63	−0.08	0.73	−0.05	−0.29	0.94	−0.32	
Psychoeducational	−0.01	0.68	−0.14	0.69	−0.19	−0.40	0.80	−0.54	
Cognitive	−0.11	0.89	−0.25	0.79	−0.16	−0.36	1.15	−0.26	
Physical	0.04	0.60	−0.02	0.62	−0.10	−0.26	0.82	−0.45	
Psychoeducat. + physical	0.03	0.75	0.06	0.49	0.04	−0.06	0.77	−0.12	
Cognitive + physical	0.10	0.59	0.16	0.52	0.11	0.33	0.80	0.35	*
Well-being									
Control	−0.17	0.76	−0.22	0.81	−0.07	−0.03	0.91	0.17	
Psychoeducational	−0.07	0.71	−0.19	0.89	−0.15	−0.35	0.98	−0.35	
Cognitive	−0.11	0.72	−0.10	0.69	0.01	−0.02	0.96	0.10	
Physical	0.13	0.70	0.12	0.70	−0.02	−0.25	1.07	−0.46	**
Psychoeducat. + physical	0.18	0.64	0.30	0.61	0.18	0.02	0.99	−0.21	***
Cognitive + physical	0.42	0.59	0.53	0.57	0.19	0.28	0.84	−0.20	***

*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$

[a] Wilcoxon–Mann–Whitney test (two-tailed) across the entire study period (longitudinal effects; Wei and Lachin 1984)

[b] Reduced case numbers, last assessment 1995

depression than the control group on the long term ($P = 0.02$; 1996 $d_+ = 0.26$). No significant differences between the control group and the other treatment groups were detected across the entire study period.

None of the training methods proved to have significant long-term effects on the very positive overall level of "well-being". The global effects documented for well-being can be attributed to the significantly higher baseline scores of certain groups.

Longitudinal analyses on the level of the individual tests substantiate these results. For example, the following longitudinal effects in cognitive functioning were proved based on psychometric tests. Compared to the control group, there were significant training gains of the combined training of cognitive and physical functions regarding information processing speed (maze test, $P \leq 0.001$), attention (color word test, $P \leq 0.001$), primary memory (sentence test, $P \leq 0.001$), secondary memory (word pairs, $P \leq 0.001$), long term memory (WAIS-information; $P \leq 0.001$) and reasoning (WAIS-similarities, $P \leq 0.001$). Memory training alone revealed significant long-term training gains in cognitive functions (compared to the control group) regarding speed of information processing (maze test, $P = 0.001$; digit symbol substitution test, $P = 0.001$), concentration and attention (aging concentration test, $P \leq 0.001$; color word test, $P \leq 0.001$), secondary memory (word pairs, $P \leq 0.001$), long-term memory (WAIS-Information, $P \leq 0.001$) and reasoning (WAIS-Similarities, $P \leq 0.001$).

These results may be influenced by the differential drop-out across the training approaches. Therefore an intention to treat analysis was done for cognitive status, cognitive impairment and independence (self and interviewer rated). However, there were the same significant results as with the non-parametrical longitudinal analysis with decreasing sample sizes. Thus the above mentioned results were replicated by an intention to treat analysis in which the "last observation carried forward method" (LOCF) was used to handle missing data. Due to limited space, these results are not presented here in detail.

Discussion

The aim of the present study was to examine the effectiveness of cognitive training, psychoeducational training and physical training on cognitive function, physical function, health status, independent living, emotional status and well-being in persons aged 75 years or older. Each training approach was implemented as a single training or as a combination of cognitive and physical training or psychoeducational and physical training. In almost all of the domains investigated, participants in the combined cognitive training and physical training displayed sustained improvements relative to the control group. The most pronounced improvements were seen in cognitive functions, cognitive impairment, health status and depression. Despite a general decrease in performance, participants in the combined cognitive training and physical training clearly outperformed their counterparts in the control group in the long term.

Combined cognitive training and physical training had a particularly positive effect on those domains where age-related losses (e.g. cognitive, physical, emotional) represent a high risk for the loss of independent living (Verbrugge et al. 1990). Furthermore, the sustained training effects, and the very large effect sizes ($d_+ = 0.75$)—in cognitive performance, in particular—up to 5 years after training show that the combined training approach can be classified as highly successful in relation to the effect sizes reported in the literature (Verhaeghen et al. 1992). It has to be considered, however, that a part of the participants continued to carry out some of the cognitive or physical training exercises on their own initiative after the intervention phase. It may be that this made a contribution to the long-standing training effects.

Consistent with previous intervention research regarding cognitive function or physical function, the elders performed better in those abilities at posttest, for which they were trained. Consistent with the results of the ACTIVE-study (Ball et al. 2002), the intervention effects remained over time. However, different to the ACTIVE-study, there was a considerable decline in measured functions in the control group. This may be due to the fact that in the present study the older people were observed over a longer time. As Ball et al. (2002) suppose, differential functional decline between trained older adults and the control group in their study would be observed in the future.

However, the present study goes beyond previous intervention studies, most of which have documented short-term gains in single performance parameters that cannot be generalized to other tasks or to everyday life (Anschutz et al. 1987; Scogin and Bienias 1988; Stigsdotter and Bäckman 1995; Verhaeghen et al. 1992; Willis and Nesselroade 1990). In the present study there was also an intervention effect of the combined cognitive and physical training on measures like everyday functioning and health status.

The effect of cognitive training on better functioning in everyday life could not be found in the ACTIVE-study. In part, this may be explained by the fact that different to the ACTIVE-study, in the present study independence was defined by a composite measure which integrated self-rated and interviewer-rated independence and the use of health care services as "meals on wheels", nursing care at home and other paid aids. A psychometric test that simulates everyday instrumental activities of daily living as the Timed IADL (Owsley et al. 2002) that was used for example in the study of Ball et al. (2002) or in the study of Edwards et al. (2005) was not yet available when the study started in 1991. However, it may be that with (I)ADL-measures, there are ceiling-effects in community-dwelling, healthy older people, so that intervention effects can only be found when the elders are followed-up for a longer time and the participants experience age-related functional loss in a higher degree.

The relatively high effects of the combined training on independent living, cognitive function and physical function, but also on health status and emotional status, that go beyond the findings of most of other intervention studies on cognitive or physical training, prompts the question of what it is that makes the specific combination of cognitive and physical training so effective. Recent findings from the above mentioned neurophysiological research (cf. Introduction) offer a plausible explanation. It could be assumed that physical training improves the metabolic activity of the brain, but this training gain can only be exploited if there is a demand for it. Such a demand is created when the brain and its individual cells are challenged in the context of specific cognitive effort. It could be through this kind of mechanism that the combined training counteracts the brain's aging process, as reflected by the cognitive performance gains and the delay of cognitive decline, in particular.

Beyond improving physical abilities, Carlson et al. (1999) suppose that exercise may also improve physiological function. As Naylor et al. (2000) found, even a regular scheduled activity program with social activities and light physical activities (e.g. going for a walk, exercises, stretching) improved memory functions and physiological parameters of brain function (e.g. EEG). Research in the field of neurophysiology has shown that systematic training programs and a stimulating learning environment can not only facilitate the development of new contacts between the nerve cells of the brain (synaptic plasticity; Bennett et al. 1996), but also prompt the formation of new neurons (neurogenesis) in adulthood (Eriksson et al. 1998; Kempermann et al. 1997; overview in Ormerod and Galea 2001). In a study by Ari et al. (2004) it was shown that long-term exercise increased maximum oxygen uptake capacity, serum testosterone, and growth hormone levels and by that supports brain function. It is assumed that higher levels of physical activity might reduce the neural resources necessary for simple cognitive demands (McDowell et al. 2003). After focused memory training, biochemical changes were found in healthy older people like an elevation of creatine and choline signals in the hippocampus. This effect was in particular found in those elders who showed lower neurometabolites at baseline and thus were considered as having a high risk for neural dysfunction (Valenzuela et al. 2003). However, because the present study was designed in 1990 when these neurophysiological insights did not exist yet, no specific neurophysiological assessments were undertaken in the present study which could prove specific neurophysiological hypotheses regarding the combined effect of cognitive and physical training. Therefore, these findings need more research regarding functional measures of brain function after combined mental and physical training. Recent empirical results regarding physical activity on cognitive function are contradictory up to now (Anstey and Christensen 2000). Most studies find a protective value regarding the development of dementia symptoms (Yaffe et al. 2001; Churchill et al. 2002; Kahana et al. 2002; Lindsay et al. 2002). However, Colcombe and Kramer (2003) conducted a meta-analysis of 18 studies and found selective effects on cognitive functions (effect sizes between 0.2 and 0.7). Correlations were found between physical activity and cognitive processes like executive functions, coordination, planning, working memory, but not with attention or visuo-spatial functions.

The positive effect of the training on depression could be explained because subjective control over cognitive and physical functions was enhanced as the participants learned about aging processes and exercises to reverse the age-related decline of these functions. Also McAuley et al. (2005) suppose that physical activity may maximize efficacy cognitions in older adults and thus improve well-being.

The finding that few short- or long-term effects of either psychoeducational training or physical training (alone or in combination) were detected can be explained as follows: although physical training seems to improve the metabolic activity of the brain, the cognitive potential released cannot be actively utilized without a specific cognitive training.

Where the psychoeducation approach is concerned, the explanation for the lack of demonstrable effects may lie rather in the educational type of intervention methods chosen. The present approach concentrated on cognitive activation as a way of dealing with everyday challenges. It can be assumed that this instructional approach focused too strongly on conveying information and advice. Too little attention was paid to the participants' invididual values and life goals or to the resources available to them in terms of, e.g. knowledge, experience, and attitudes, for the program to trigger lasting changes in everyday behavior. A preventive approach based almost exclusively on information and education thus seems to be of little value. On the other side, the cognitive stimulation seems to be too unspecific, compared to cognitive training.

There are some methodological shortcomings and limitations of the study to be discussed. First, the assessors doing the psychometric tests and interview ratings or medical examination, were not blind for the training group of the participants. However, beyond the results of psychometric tests, interviewer-ratings or the examination or organic function, also the use of health-services (e.g. "meals on wheels", nursing care at home) as a more objective measure was lower for the participants in the combined cognitive/physical training, so the results of cognitive tests, interviewer-ratings and medical examination are in concordance.

Second, there was a selective drop-out of participants with a greater cognitive and/or physical decline, and drop-outs were significantly older than participants. However, this result might indicate, that cognitive/physical training is the more convenient and effective the earlier it begins. This means that the cognitive and physical training that was developed in the present study has its particular value to prevent or to delay cognitive or physical decline. As it was the case in the experimental study of Ball et al. (2002), there is the methodical problem that intervention effects may be detected not before the ageing process causes a greater amount of cognitive or physical decline so that the differences between the experimental group and a no-treatment-group are more distinctive. To evaluate the effects of a preventive training approach therefore requires a long-term follow-up as it was realized the present study over 5 years.

Third, because of the described organizational problems regarding random assignment to the groups and the high drop-out-rate, that resulted mainly from physical diseases or death, there were only small sample sizes in intervention groups with physical training. As mentioned above, older persons with major health limitations that allowed no physical training should be excluded by a self-administered screening questionnaire. However, more participants than expected turned out to suffer from medical conditions (e.g. heart disease) at the first time in the medical baseline assessment. Because physical training and the combined training approaches (cognitive and psychoeducational training, respectively, with physical training) should not be excluded completely, small sample sizes were accepted despite the power problems regarding significance tests. However, despite the low participant numbers resulting from sample attrition, the effects discerned in the yearly repeated assessments were very consistent and stable over 5 years, highly significant and—in cognitive status and cognitive impairment, respectively—very strong. None of the other interventions had effects comparable to those of combined cognitive and physical training—in terms of either effect sizes or stability over time.

Fourth, only few effects relative to the multitude of outcome measures reached statistical significance and have to be interpreted cautiously considering type II error. Therefore, according to the explorative character of the study, the results should be considered as descriptive (cf. Abt 1987).

Nevertheless, the study reveals that in particular the combined training of cognitive and physical functions may be considered as a promising approach to prevent the loss of independent living in a long term perspective, even in adults above 75 years of age.

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