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REVIEW ARTICLE

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A systematic review on prognostic factors and models for changes in quality of life and depressive symptoms after multi-domain cognitive training in healthy older adults: Who benefits?

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Abstract

Background: As we age, cognitive abilities decline which can lead to a decrease in quality of life (QoL) and an increase in depressive symptoms even in healthy (i.e., non-clinical) older adults. Cognitive trainings (CT) are a promising approach to not only improve cognition, but also QoL and mood. However, it is unclear which prognostic factors are associated with changes in QoL and depression after CT.

Objective: To identify prognostic factors and models of changes in QoL and depressive symptoms after a multi-domain CT in healthy older adults.

Methods: MEDLINE, Web of Science Core Collection, CENTRAL and PsycInfo were systematically searched for multi-domain CT studies in healthy older adults until August 2022. Studies investigating prognostic factors and/or models on QoL and depressive symptoms were included. Risk of bias was assessed using the QUIPS and the PROBAST tool.

Results: Our search revealed $N = 12{,}916$ studies, of which only 6 could be included in the review. Prognostic factors included were sociodemographics, cognitive reserve, cognitive baseline level, and cognitive change. However, data were too rare and heterogenous regarding the assessment measures of QoL and depressive scores, the used multi-domain CT and the investigated prognostic factors to draw clear conclusions or conduct meta-analyses.

Conclusion: There is an urgent need for research on prognostic factors and models of changes in QoL and depressive symptoms after CT in healthy older participants as they could help to tailor interventions to individuals in terms of future precision medicine approaches.

KEYWORDS
cognitive training, depression, healthy older adults, prognostic factors, prognostic models, quality of life

Key points

- Although cognitive training (CT) is known to have positive effects on quality of life (QoL) and depression, a systematic review examining prognostic factors and models for these effects was lacking.
- Prognostic factors included were sociodemographics, cognitive reserve, cognitive baseline level, and cognitive change.
- Data were too heterogenous to draw clear conclusions or conduct meta-analyses.
- Future research should enlighten which factors and models predict CT changes on QoL and depression to foster individualized cognitive interventions.

1 | INTRODUCTION

In the context of research on cognitive aging, the constructs of quality of life (QoL) and psychological well-being have gained more relevance over the past years. QoL is composed of multidimensional subjective and objective components[1,2] that concretely expresses both how satisfied a person is with his/her life and the degree of well-being and welfare he/she is experiencing[3]. Consequently, physical as well as psychological components of QoL are negatively associated with depressive symptoms, such as low mood, lack of interest in activities or feelings of worthlessness with reduced self-efficacy.[4] Reduced self-efficacy includes own judgements and feelings of being unable to control one's own actions, that is, in order to achieve personal satisfaction, and is associated with higher rates of depressive symptoms.[5]

Even in healthy aging, a reduced QoL[6] and various symptoms associated with depression[7] have been reported as a consequence of age-related cognitive decline (e.g., memory, problem-solving). Notably, several systematic reviews and meta-analyses show that cognitive training (CT) is a promising non-pharmacological intervention approach to maintain or even improve cognitive performance of healthy older adults.[8,9] Different forms of CT need to be taken into consideration. One important differentiation is that between "single-domain CT" which only targets specific cognitive domains (e.g., memory or working memory training) and "multi-domain CT" in which several cognitive domains are addressed. Especially multi-domain CT is extensively researched, as it is more closely related to real-life demands than single-domain training.[10] Also, the multi-domain approach is frequently applied in commercially available "brain games," such as Nintendo's Dr Kawashima's Brain Training, which are widely used in the older population.[11] Notably, computerized multi-domain CT was not only the most efficacious CT approach in a recent network meta-analysis regarding the outcomes global cognition and individual cognitive domains.[12] Several randomized controlled trials also showed an improvement in QoL after multi-domain CT,[13,14] and a meta-analysis reports beneficial effects on everyday functioning after multi-domain CT in healthy and pathological aging.[15] Additionally, CT can have further beneficial far transfer effects on depressive mood in pathological aging as suggested by a recently published meta-analysis.[16] Single studies revealed similar effects on general depressive mood in healthy aging[17] and provide further evidence for specific beneficial effects on participants' cognitive self-efficacy (i.e., exerting some control over or induce changes in own cognitive skills).[18]

Even though CT-induced changes in QoL, depressive symptoms, and related constructs have been studied in the past, it remains unclear, whether or not specific characteristics (e.g., sociodemographic, (neuro-) psychological) of individuals are associated with those changes, that is, can be regarded as prognostic factors of responsiveness to CT with regard to these outcomes. Prognostic factors are defined as a single factor from which risks can be calculated for a specific endpoint.[19] Yet, as individual risk prediction is usually poor when it is only based on a single factor, a formal combination of multiple predictors from which risks of a specific endpoint can be calculated for individuals can be used which is called prognostic model.[20] Prognostic model research has three main phases: model development (including internal validation), external validation, and investigations of impact in clinical practice.[20] Prognostic factors, such as sociodemographic, neuropsychological or neural parameters, could facilitate the process of individual decision-making with regard to interventions improving QoL and (early) signs of depression in healthy adults. So far, systematic reviews exist on prognostic factors[21] and models[22] on memory training and on multi-domain CT responsiveness[23]; however, they do not take into account patient-related outcomes as QoL and depressive symptoms, but rather cognitive outcomes. Thus, gaining further knowledge on potential predictors of beneficial changes in QoL and depressive symptoms after CT would be highly relevant for decision support to realize personalized medicine, for example, in the context of preventing cognitive decline and depressive symptoms.

Therefore, due to the special relevance of multi-domain CT, the aim of the present systematic review was to identify prognostic factors and models of changes in QoL and depressive symptoms especially after a multi-domain CT in healthy older adults.

2 | METHODS

The present systematic review is part of a larger project on identifying prognostic factors and models of changes on several outcomes after multi-domain training. Due to our broad systematic search strategy, we were able to conduct two sub-projects: first, a review

addressing prognostic factors and models of changes on cognitive outcomes (e.g., global cognition, executive function[23]). Second, the present review focusing on QoL and depressive symptoms as outcomes. For a detailed description of the methods used, see Roheger et al.[23] The entire project was pre-registered (https://www.crd.york.ac.uk/prospero/, ID: CRD42020147531). The reporting follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guideline for systematic reviews and meta-analysis.[24]

2.1 | Systematic literature search, study selection, and eligibility criteria

MEDLINE (via Ovid), Web of Science Core Collection, CENTRAL and PsycInfo were systematically searched for relevant studies up to July 2019 and further updated with studies published until August 2022 using the following search terms: "healthy aging", "older adults", "cognitive aging", "training", "cognitive training", "brain training", "quality of life", "QoL", "life satisfaction", "well-being".

We defined eligibility criteria in terms of population, interventions, comparators, outcomes and timing (PICOT). The review focused on peer-reviewed studies in English and German, which investigated prognostic factors and models of changes in QoL and depressive symptoms after multi-domain CT with no limitations regarding publication date. Studies investigating healthy older (age ≥55 years) participants (P) were included, thereby excluding data from participants with diagnosis of cognitive impairment or dementia, neurological and/or psychiatric diseases, assessed at least via self-report.

Regarding the included prognostic factors and models, all prognostic factors (e.g., sociodemographic factors, brain imaging parameters, genetic parameters, blood factors, personality traits, cognitive abilities at the entry of the training, different training characteristics, e.g., intensity of the trainings, etc.) and all prognostic models were included in the review. In order to depict the current state of prognostic research in the context of CT-induced changes in QoL and/or depressive symptoms, we only included published studies explicitly reporting results of prognostic analyses. We did not request data from authors of CT-studies to conduct post-hoc analyses.

We defined multi-domain CT as a CT that includes training tasks of at least two cognitive domains. The training should consist of at least 90% of cognitive exercises (next to e.g., physical exercises, diets) with a minimum of 2 sessions in total (I). No pre-assumptions about comparator interventions were made (C).

Studies including data on prognostic factors and/or models, which investigate changes in QoL or depressive status after training as an outcome measured with established objective (neuro-) psychological scales were included (O). QoL served as our primary outcome, whereas depressive symptoms were chosen as our secondary outcome as they are closely related to QoL.[25]

The factor measurement of the included studies had to be conducted before the training started at baseline, and there was no limitation regarding post-measurements of outcomes or the length of the follow-ups (T).

2.2 | Data extraction and quality assessment

Data were extracted by two review authors independently (HLJ and MR; AKF and EK for the update search) according to the Critical appraisal and data extraction for systematic reviews of prediction modeling studies_ prognostic factors (CHARMS_PF) checklist.[26] The authors assessed the extracted studies for the risk of bias independently. For prognostic factor studies, the Quality in Prognosis Studies (QUIPS) checklist, developed by Hayden and colleagues (2013) was used,[27] prognostic model studies were assessed using the "Prediction model Risk of Bias Assessment Tool (PROBAST)".[28]

2.3 | Statistical analysis

In the pre-registration of the review, it was planned that, if participants' and methodological characteristics of the individual studies were sufficiently homogeneous, statistical measures for model performance (e.g., statistics for discrimination and calibration) and model parameters (e.g., regression coefficients) should be pooled meta-analytically across studies. However, we could not extract enough data to conduct a meta-analysis.

3 | RESULTS

3.1 | Study selection

The PRISMA diagram in Figure 1 shows the total number of retrieved references of included and excluded studies, as well as reasons for exclusion. In total, N = 12,916 studies were identified through the database search. After removing the duplicates, n = 9198 studies were screened. We assessed n = 667 full-texts for eligibility. We could identify n = 28 for the overall project identifying prognostic factors and models of changes on different outcomes (e.g., memory, attention, QoL) after multi-domain training. There were n = 6 studies investigating specifically depressive symptoms and/or QoL as outcomes. Therefore, n = 6 studies were finally included in the present review. With only six included studies, a meta-analysis could not be conducted.

3.2 | Study and participant characteristics

An overview of study and participant characteristics including study type (prognostic factor or model study), outcome, outcome definition, participants' age, sex, and education as well as information on the conducted training are outlined in Table 1.

In total, five of the investigated studies were prognostic factor studies[29–33] and one study investigated a prognostic model.[34] Sample

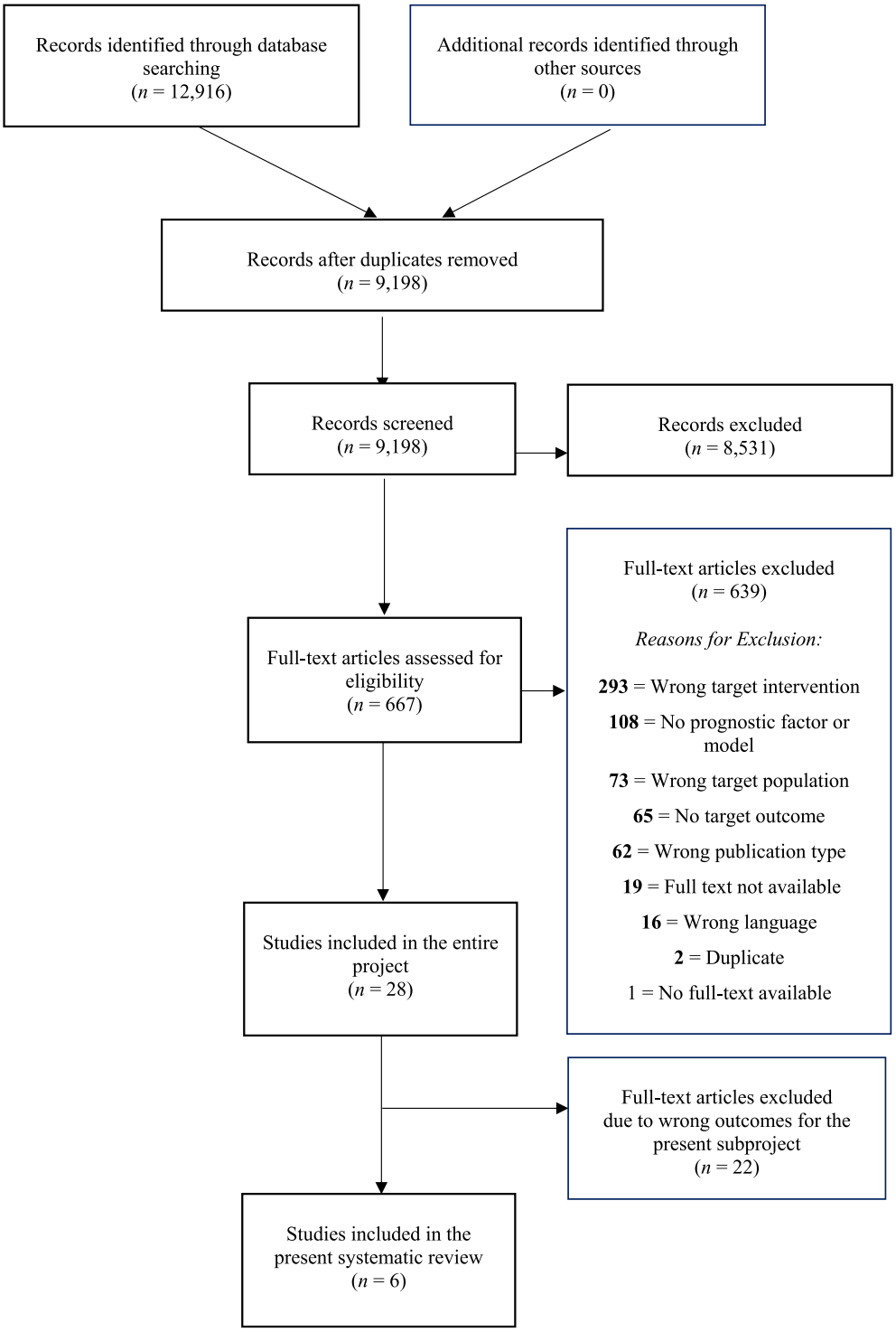


FIGURE 1 PRISMA diagram showing the study selection process.

sizes in the prognostic factor studies ranged from $n = 14$[33] to $n = 60$.[32] Mean age in the prognostic factor studies ranged from 67.90 years[29] to 82.21 years.[33] Only three studies reported sex ratios of the participants with slightly more male than female participants.[29,31,32] One prognostic factor study did not report any sociodemographic characteristics.[30] In the prognostic model study,[34] 27 participants were included with a mean age of 71.67 years, no sex-ratio was reported.

3.3 | Outcome measurements

Four of the prognostic factor studies investigated QoL as their main outcome[29–32] using different standardized assessment tools: WHO-5 Well-Being Index,[29] the World Health Organisations Short Assessment of Quality of Life (WHOQOL-BREF),[31] the Satisfaction with Life Scale (SWLS),[32] and the Short Questionnaire on Quality of Life (CUBREVACI).[30] The WHO-5 Well-Being index covers five positively

TABLE 1 Study characteristics.

Study	Study type		Investigated prognostic factor/model & result	Outcome		Outcome definition	Participants			Training
	Prognostic model	Prognostic factor		Quality of life	Depressive symptoms		*n*[a]	Age M (SD)	Sex	
Bures et al.[29]		x	Education ↑ Female sex ↑	x		Well-being assessed with the WHO-5 well-being index	37	67.90 (5.59)	23♂, 14♀	Individualized cognitive training
Fernandez-Prado et al.[30]		x	Cognitive development (measured with change score of Lobo's cognitive mini-exam) ↑*	x		QoL assessed with short questionnaire on quality of life (CUBREVACI)	n.a.	n.a.	n.a.	Cognitive stimulation program
McDougall & House[31]		x	Wechsler adult Intelligence scale (WAIS) sub-test change score on digit span fw, bw & total score ↑*	x		QoL assessed with world health Organisation's shorter assessment of quality of life (WHOQOL-BREF)	21	74.81 (7.85)	11♂, 10♀	Nintendo 'brain training'
Montoya-Murillo et al.[32]		x	Cognitive reserve (measured with the cognitive reserve questionnaire) -	x	x	QoL assessed with satisfaction with life scale (SWLS); depression assessed with geriatric depression scale (GDS)	60	78.62 (8.43)	23♂, ♀37	Cognitive rehabilitation program 'rehacop'
Nouchi et al.[34]	x		Age -Sex -Mini mental state examination (MMSE) at baseline -Pre-score of profile of mood state examination (POMS2) -		x	Moods assessed with POMS2—short version	27	71.67(3.62)	n.a.	Cognitive training game for car driving group
Otsuka et al.[33]		x	Cognitive changes ↓ (measured with frontal assessment battery [FAB])		x	Depressive symptoms measured with GDS	14	82.21 (2.89)	n.a.	Atama-nodojo

Abbreviations: M, Mean; SD, Standard Deviation.

[a]Total number of participants in cognitive training group of older participants; ↑ = the higher the factor, the higher the outcome; ↓ = the higher the factor, the lower the outcome, - = no direction of effect reported, * = significant effect.

worded items, related to positive mood, vitality and general interests, and measures emotional functioning. Yet, the WHO-5 Well-Being index is also frequently used as a screening tool for depression. The WHOQOL-BREF comprises 26 items to assess QoL in four domains: physical, psychological, social, and environment. THE CUBREVACI is also based on a multidimensional construct of QoL and health similar to the WHOQOL-BREF. The SWLS is a 5-item instrument focusing on life satisfaction in general.

Two prognostic factor studies[32,33] and the included prognostic model study[34] used depressive symptoms as their main outcome. In the prognostic factor studies[32,33] the Geriatric Depression Scale (GDS) was used to assess depressive symptoms. The GDS consists of 15 items on general mood and depressive symptoms. Nouchi et al.[34] used the Profile of Mood State Second Edition-short version (POMS2) test to assess depressive symptoms. The POMS2 comprises 35 items measuring Tension-Anxiety, Depression-Dejection, Anger-Hostility, Vigor-Activity, Fatigue-Inertia, Confusion-Bewilderment, and Friendliness.

3.4 | Content and characteristics of multi-domain CT

Characteristics of multi-domain CT used in the included studies are highly heterogeneous. Only two interventions were conducted in a group setting consisting of structured work sessions including different training activities.[30,32] All other trainings were conducted on digital devices, either on the participants' television at home,[29,34] on a television at the university,[33] or on a Nintendo DS.[31] Content of the multi-domain trainings differed: one training focused on driving-related cognitive tasks such as processing speed, dual attention, and speed prediction,[34] three trainings targeted multiple specific cognitive tasks such as word retrieval or orientation tasks,[29,30,32] and the remaining two focused on playing various games in which multiple cognitive domains were trained.[31,33]

Yet, included multi-domain CT also varied in frequency and duration. Four studies[29,30,33,34] reported the training duration ranging from 6 weeks[34] to 9 months.[30] Training session duration was either self-determined,[31] or ranged from 45[33] to 90 min.[30] All in all, the total time of training varied from 480[29] to 6480 min.[30]

3.5 | Prognostic factors and models of changes after multi-domain CT

As our study pool consisted of only five prognostic factor studies and one prognostic model study, no clear patterns regarding prognostic factors and models of changes in QoL and depressive symptoms after multi-domain CT in healthy older adults could be detected. Investigated prognostic factors were: Age (1 study), sex (2 studies), education (1 study), cognitive reserve (1 study), and cognitive scores (pre-test and change scores; 4 studies). An overview of the results is displayed in Table 1.

Regarding the outcome QoL, all included studies were prognostic factor studies.[29–31] One study found that higher education and being female predicted improvements of QoL.[29] This study calculated two separate mediation analyses to investigate the two different potential prognostic factors. Another study examined a possible moderation effect of cognitive reserve on QoL within a linear regression analysis but could not identify this variable as a significant prognostic factor.[32] One study investigated training-induced changes in the digit span test.[31] Standardized differences of the digit span forward (measuring short-term memory), backwards (measuring working memory), and a total score were analyzed using separate correlation analysis for each potential prognostic factor, showing that higher change scores predicted higher scores in QoL, that is, improvements in the digit span test predicted improvements in QoL from baseline to post-test.[31] Furthermore, one study assessing cognitive changes from pre-to post-test found that improvement in cognitive development significantly predicted improvements in QoL.[30]

Depressive symptoms were investigated in two prognostic factor studies[32,33] and one prognostic model study.[34] In a prognostic factor study, higher beneficial cognitive changes predicted less depressive symptoms.[33] Cognitive reserve could not be identified as a significant prognostic factor for depression by Montoya-Murillo et al.[32] In the prognostic model study, none of the investigated potential prognostic factors (age, sex, MMSE at baseline, nor the pre-score of Profile of Mood State Examination) were significantly associated with depressive symptoms.[34]

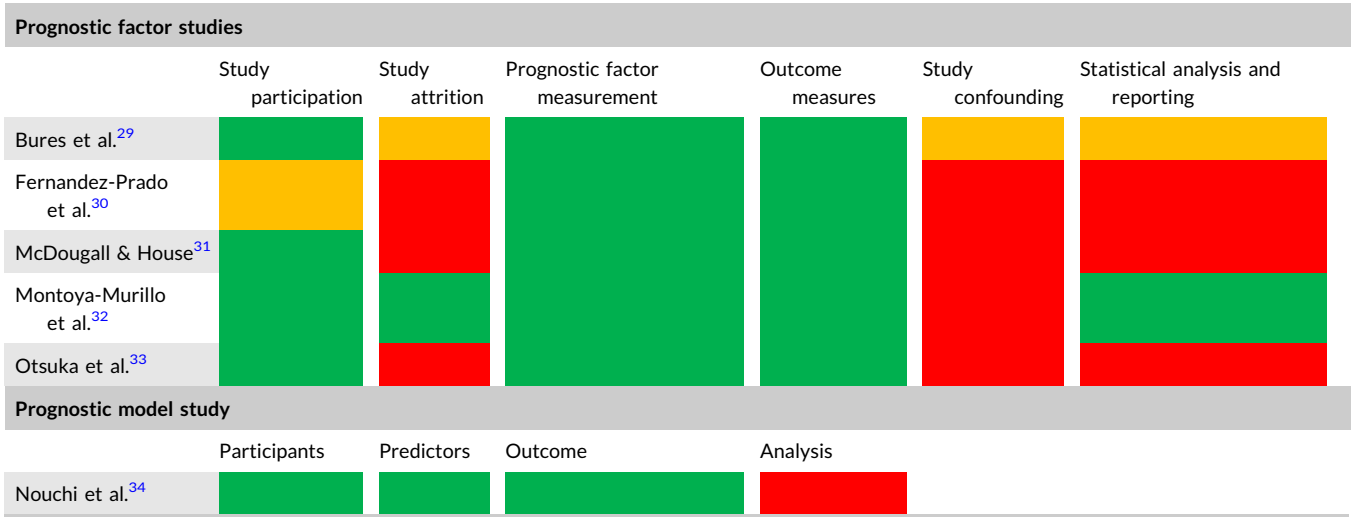
4 | RISK OF BIAS

Risk of bias for prognostic factor studies was assessed with the QUIPS tool[27] and shows medium to high risks of bias in all studies (Table 2). This is mainly due to the fact that clear reporting of the statistical results was lacking and all studies except two[29,32] used correlations to calculate prognostic factors. Furthermore, detailed information on study attrition and possible study confounders was mostly missing. It should be noted that prognostic factors and all outcomes of interest were clearly defined and adequately measured in all studies. Risk of bias in the prognostic model study was assessed with the PROBAST tool[28] and showed that there is also room for improvement when conducting the statistical analysis, as no model validation was conducted and the reporting was not exhaustive.

5 | DISCUSSION

This is the first systematic review that investigates prognostic factors and models for changes in QoL and depressive symptoms after multi-domain CT in healthy older adults. Our results show that first, there is a high need for more prognostic research on multi-domain CT as we could only include 5 prognostic factors and one prognostic model study. Second, prognostic factors included sociodemographics, cognitive reserve, cognitive baseline level, and cognitive change.

TABLE 2 Risk of bias assessment for prognostic factor and prognostic model studies.



Note: Red color indicates a high risk of bias, yellow color indicates a moderate risk of bias, green color indicates a low risk of bias, assessed with the QUIPS tool for prognostic factor Studies[27] and the PROBAST tool[28] for prognostic model studies.

Third, risk of bias assessment showed methodological shortcomings regarding prognostic statistical analyses and reporting of the prognostic factors and models in the included studies. Fourth, instruments to assess QoL and depressive scores were heterogeneous, as well as the conducted multi-domain CTs, and the investigated predictors. Due to these methodological limitations, the high heterogeneity in scales and trainings, and the limited data, no clear results can be drawn. Tentatively, data points in the direction that higher cognitive change scores are associated with higher scores in QoL measures and lower scores in depressive symptoms measurement after conducting a multi-domain CT– in other words, higher CT-related cognitive gains are related to higher improvements in QoL and less depressive symptoms after multi-domain CT. However, as indicated, these results must be interpreted with caution.

Due to the small number of included studies, the present review can be classified an empty review (defined as a review without any results or without any studies). According to Cochrane standards and current literature "empty reviews are important, as they tell us who is undertaking a review and thus interested in the topic, can highlight major research gaps and indicate the state of the evidence at a point in time. They can also justify further research and/or funding and even highlight potential harms of an intervention".[35] Therefore, one of our main results of the present review is that QoL and depressive symptoms are highly under-investigated even though those outcomes are highly relevant as they have a huge impact on everyday life. Increasing QoL in older age and decreasing depressive symptoms is of utmost importance, particularly as subjective wellbeing and health are closely related. Focusing on cognitive health, a common approach to prevent cognitive decline in older age is multi-domain CT.[15] As multi-domain CT approaches primarily target the training of different cognitive functions, QoL and mood-related outcomes are often assessed as so-called far transfer (i.e., not directly trained) outcomes. Training-induced far transfer effects on mood-related outcomes and QoL have become more frequent in research.[36] While the effectiveness of CT on those outcomes has been established in the past, it remains unclear which specific factors predict those training-related far transfer changes. Gaining knowledge in this area could be helpful in the context of personalized medicine in order to define specific groups who may benefit from a specific (cognitive) intervention.

Results of the present review show that prognostic factor and model studies investigated here show methodological shortcomings and therefore (together with the fact that data is limited per se), conclusions are challenging. Even though several guidelines for the adequate conduction and reporting of prognostic factor and model studies exist,[20] as well as suggestions for specific statistical analysis in CT prognostic research,[37] data analysis and reporting in the included studies is often incomplete. The present review again underlines the need to use these recommendations with the aim to generate evidence-based, reproducible, and reliable results.

Keeping the shortcomings in mind, results point in the direction that higher cognitive change scores lead to higher changes in QoL measures and lower scores in depressive symptoms measurement from pre-to post-training. This finding extends previous research on the relationship between health and subjective wellbeing. More precisely, a bidirectional relationship between the two constructs can be considered: On the one hand, subjective wellbeing and QoL seem to be protective factors for physical and mental health.[38] On the other hand, physical[39] and mental functioning[40] determine QoL. Focusing on cognitive functioning and subjective wellbeing, it is well established that (1) depressive symptoms predict cognitive decline[41] and that (2) cognitive decline affects QoL.[42] Basak et al.[15] found that participating in a regular multi-domain CT has positive far transfer effects on everyday functioning in healthy older adults, indicating that CT may enhance functional independence in everyday situations such as meal preparation, telephone use, or money management. Complementary, everyday functioning is positively associated with QoL.[43] Our results extend previous research and provide further

evidence that the largest gain in QoL and depressive symptoms is yielded in persons, who also cognitively benefit most from pre-to post training. This finding can also be discussed in the context of cognitive self-efficacy. As CT can improve participants' cognitive self-efficacy,[18] self-evaluations of own competences to control and change cognitive skills increase. In addition, cognitive self-efficacy is positively correlated with cognitive performance[44] and QoL, and negatively associated with depressive symptoms in older adults.[45] Referring to the results of the present review, cognitively benefiting from multi-domain CT might be associated with improvements of cognitive self-efficacy leading to an increase in QoL and a decrease in depressive symptoms. However, this moderating role of cognitive self-efficacy requires empirical investigation in the future. Surprisingly, only two of the included studies[29,31] reported a sex ratio of the participants, even though previous literature suggests that sex plays an important role when it comes to predicting success of CT. A recent post-hoc analysis of two online CTs (a general cognitive training and a reasoning cognitive training) including more than 4000 participants showed that being female predicted grammatical reasoning scores at 6 weeks and 3 months of reasoning training,[46] and at 6 weeks in the general CT group.[47] As there are substantial sex differences with regard to the prevalence of depressive symptoms (with females experiencing around twice as often major depressive episodes than males[48]) and consequently on the perceived QoL, sex should be integrated in future studies as an important predictor for CT success in participant-related variables such as QoL and depressive levels.

Some limitations of this review must be considered. First, as only English and German articles were included, this implies a possible limitation. The present review can be regarded as an empty review which means that data were too rare and heterogeneous to draw a clear conclusion or to perform a meta-analysis (as we registered in our pre-registration). Therefore, our review is a "wake up-call" for the current research field of prognostic factors for CT-induced changes in QoL and depressive symptoms as it highlights major research gaps, indicates the state of the evidence at the current point of time and justifies further research in this potential area.[35] This is also highlighted by our update search covering published trials between July 2019 and August 2022 which resulted in only one additional study that could be included. A further advantage is that we could identify important methodological shortcomings regarding the statistics and reporting.

Summarized, this is the first review investigating prognostic factors and models of changes in QoL and depressive symptoms after multi-domain CT in healthy older adults. It shows methodological shortcomings and emphasizes the need of elaborated prognostic factor studies with larger sample sizes and clear reporting standards. As identifying patterns of training success prediction might help to tailor CTs to individuals with different profiles, further research should focus and unravel prediction patterns and their underlying mechanisms with the aim to optimize the wellbeing of participants in a personalized medicine approach. This review (carefully) suggests that higher CT-related cognitive gains are related to higher improvements in QoL and depressive symptoms. Further research is needed to evaluate this finding in more detail, for example, by looking at prognostic factors after adjusting for cognitive improvement. In the context of personalized medicine in clinical practice, predictors easily to assess (e.g., using questionnaires), such as sociodemographic variables (e.g., age, sex, education) or psychological variables (e.g., Big Five personality traits), could be of particular interest. Furthermore, to understand plasticity mechanisms, also biological variables (e.g., hippocampal volume, genetics, nerve growth factors) should be investigated. Finally, future approaches could include meta-analyses of individual patient data in order to adjust effect sizes for confounding factors.

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CONFLICT OF INTEREST STATEMENT

Hannah Liebermann-Jordanidis, Ann-Kristin Folkerts, Fabian Krohm, and Annegret Alfter do not declare any conflicts of interests.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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REFERENCES

1. Cummins RA. Moving from the quality of life concept to a theory. *J Intellect Disabil Res JIDR (J Intellect Disabil Res)*. 2005;49(Pt 10):699-706. https://doi.org/10.1111/j.1365-2788.2005.00738.x
2. Horner B, Boldy DP. The benefit and burden of "ageing-in-place" in an aged care community. *Aust Health Rev A Publication of the Australian Hospital Association*. 2008;32(2):356-365. https://doi.org/10.1071/ah080356
3. The WHO-QoL Group. The World Health Organization quality of life assessment (WHOQOL): development and general psychometric properties. *Soc Sci Med*. 1998;46(12):1569-1585. https://doi.org/10.1016/S0277-9536(98)00009-4
4. Cao W, Guo C, Ping W, Tan Z, Guo Y, Zheng J. A community-based study of quality of life and depression among older adults. *Int J Environ Res Publ Health*. 2016;13(7):693. https://doi.org/10.3390/ijerph13070693
5. Maciejewski PK, Prigerson HG, Mazure CM. Self-efficacy as a mediator between stressful life events and depressive symptoms. Differences based on history of prior depression. *Br J Psychiatry J Ment Sci*. 2000;176(4):373-378. https://doi.org/10.1192/bjp.176.4.373
6. Klimova B, Valis M, Kuca K. Cognitive decline in normal aging and its prevention: a review on non-pharmacological lifestyle strategies. *Clin Interv Aging*. 2017;12:903-910. https://doi.org/10.2147/CIA.S132963
7. Schweitzer I, Tuckwell V, O'Brien J, Ames D. Is late onset depression a prodrome to dementia? *Int J Geriatr Psychiatr*. 2002;17(11):997-1005. https://doi.org/10.1002/gps.525

8. Shah TM, Weinborn M, Verdile G, Sohrabi HR, Martins RN. Enhancing cognitive functioning in healthly older adults: a systematic review of the clinical significance of commercially available computerized cognitive training in preventing cognitive decline. *Neuropsychol Rev*. 2017;27(1):62-80. https://doi.org/10.1007/s11065-016-9338-9
9. Van Balkom TD, van den Heuvel OA, Berendse HW, van der Werf YD, Vriend C. The effects of cognitive training on brain network activity and connectivity in aging and neurodegenerative diseases: a systematic review. *Neuropsychol Rev*. 2020;30(2):267-286. https://doi.org/10.1007/s11065-020-09440-w
10. Binder JC, Martin M, Zöllig J, et al. Multi-domain training enhances attentional control. *Psychol Aging*. 2016;31(4):390-408. https://doi.org/10.1037/pag0000081
11. Simons DJ, Boot WR, Charness N, et al. Do "Brain-Training" programs work? *Psychol Sci Publ Interest*. 2016;17(3):103-183. https://doi.org/10.1177/1529100616661983
12. Lampit A, Malmberg Gavelin H, Sabates J, et al. Computerized cognitive training in cognitively healthy older adults: a systematic review and network meta-analysis. 2020. https://www.medrxiv.org/content/10.1101/2020.10.07.20208306v1
13. Ayán C, Carvalho P, Varela S, Cancela JM. Effects of water-based exercise training on the cognitive function and quality of life of healthy adult women. *J Phys Activ Health*. 2017;14(11):899-904. https://doi.org/10.1123/jpah.2017-0036
14. Barboza NM, Terra MB, Bueno MEB, Christofoletti G, Smaili SM. Physiotherapy versus physiotherapy plus cognitive training on cognition and quality of life in Parkinson disease: randomized clinical trial. *Am J Phys Med Rehabil*. 2019;98(6):460-468. https://doi.org/10.1097/phm.0000000000001128
15. Basak C, Qin S, O'Connell MA. Differential effects of cognitive training modules in healthy aging and mild cognitive impairment: a comprehensive meta-analysis of randomized controlled trials. *Psychol Aging*. 2020;35(2):220-249. https://doi.org/10.1037/pag0000442
16. Chan JYC, Chan TK, Kwok TCY, Wong SYS, Lee ATC, Tsoi KKF. Cognitive training interventions and depression in mild cognitive impairment and dementia: a systematic review and meta-analysis of randomized controlled trials. *Age Ageing*. 2020;49(5):738-747. https://doi.org/10.1093/ageing/afaa063
17. Nouchi R, Saito T, Nouchi H, Kawashima R. Small acute benefits of 4 Weeks processing speed training games on processing speed and inhibition performance and depressive mood in the healthy elderly people: evidence from a randomized control trial. *Front Aging Neurosci*. 2016;8:302. https://doi.org/10.3389/fnagi.2016.00302
18. West RL, Bagwell DK, Dark-Freudeman A. Self-efficacy and memory aging: the impact of a memory intervention based on self-efficacy. *Aging Neuropsychol Cognit*. 2008;15(3):302-329. https://doi.org/10.1080/13825580701440510
19. Riley RD, Hayden JA, Steyerberg EW, et al. Prognosis Research Strategy (PROGRESS) 2: prognostic factor 656 research. *PLoS Med*. 2013;10(2):e1001380. https://doi.org/10.1371/journal.pmed.1001380
20. Steyerberg EW, Moons KGM, van der Windt DA, et al. Prognosis research strategy (PROGRESS) 3: prognostic model research. *PLOS Med*. 2013;10(2):e1001381. https://doi.org/10.1371/journal.pmed.1001381
21. Roheger M, Kalbe E, Corbett A, Brooker H, Ballard C. Lower cognitive baseline scores predict cognitive training success after 6 months in healthy older adults: results of an online RCT. *Int J Geriatr Psychiatr*. 2020;35(9):1000-1008. https://doi.org/10.1002/gps.5322
22. Roheger M, Kalbe E, Corbett A, Brooker H, Ballard C. Predictors of changes after reasoning training in healthy adults. *Brain Behav*. 2020;10(12):e01861. https://doi.org/10.1002/brb3.1861
23. Roheger M, Liebermann-Jordanidis H, Krohm F, Adams A, Kalbe E. Prognostic factors and models for changes in cognitive performance after multi-domain cognitive training in healthy older adults: a systematic review. *Front Hum Neurosci*. 2021;15:636355. https://doi.org/10.3389/fnhum.2021.636355
24. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *BMJ Clin Res (Ed.)*. 2009;339:b2535. https://doi.org/10.1136/bmj.b2535
25. Wang J, Wu X, Lai W, et al. Prevalence of depression and depressive symptoms among outpatients: a systematic review and meta-analysis. *BMJ Open*. 2017;7(8):e017173. https://doi.org/10.1136/bmjopen-2017-017173
26. Moons KGM, Groot JAHde, Bouwmeester W, et al. Critical appraisal and data extraction for systematic reviews of prediction modelling studies: the CHARMS checklist. *PLOS Med*. 2014;11(10):e1001744. https://doi.org/10.1371/journal.pmed.1001744
27. Hayden JA, van der Windt DA, Cartwright JL, Côté P, Bombardier C. Assessing bias in studies of prognostic factors. *Ann Intern Med*. 2013;158(4):280-286. https://doi.org/10.7326/0003-4819-158-4-201302190-00009
28. Wolff RF, Moons KGM, Riley RD, et al. Probast: a tool to assess the risk of bias and applicability of prediction model studies. *Ann Intern Med*. 2019;170(1):51-58. https://doi.org/10.7326/M18-1376
29. Bureš V, Čech P, Mikulecká J, Ponce D, Kuca K. The effect of cognitive training on the subjective perception of well-being in older adults. *Peer. J*. 2016;4:e2785. https://doi.org/10.7717/peerj.2785
30. Fernández-Prado S, Conlon S, Mayán-Santos JM, Gandoy-Crego M. The influence of a cognitive stimulation program on the quality of life perception among the elderly. *Archives Gerontology Geriatrics*. 2012;54(1):181-184. https://doi.org/10.1016/j.archger.2011.03.003
31. McDougall S, House B. Brain training in older adults: evidence of transfer to memory span performance and pseudo-Matthew effects. *Aging Neuropsychol Cognit*. 2012;19(1-2):195-221. https://doi.org/10.1080/13825585.2011.640656
32. Montoya-Murillo G, Ibarretxe-Bilbao N, Peña J, Ojeda N. Effects of cognitive rehabilitation on cognition, apathy, quality of life, and subjective complaints in the elderly: a randomized controlled trial. *Am J Geriatr Psychiatr*. 2020;28(5):518-529. https://doi.org/10.1016/j.jagp.2019.10.011
33. Otsuka T, Tanemura R, Noda K, Nagao T, Sakai H, Luo Z-W. Development of computer-aided cognitive training program for elderly and its effectiveness through a 6 Months group intervention study. *Curr Alzheimer Res*. 2015;12(6):553-562. https://doi.org/10.2174/1567205012666150530202335
34. Nouchi R, Kobayashi A, Nouchi H, Kawashima R. Newly developed TV-based cognitive training games improve car driving skills, cognitive functions, and mood in healthy older adults: evidence from a randomized controlled trial. *Front Aging Neurosci*. 2019;11:99. https://doi.org/10.3389/fnagi.2019.00099
35. Yaffe J, Montgomery P, Hopewell S, Shepard LD. Empty reviews: a description and consideration of Cochrane systematic reviews with no included studies. *PloS one*. 2012;7(5):e36626. https://doi.org/10.1371/journal.pone.0036626
36. Motter JN, Grinberg A, Lieberman DH, Iqnaibi WB, Sneed JR. Computerized cognitive training in young adults with depressive symptoms: effects on mood, cognition, and everyday functioning. *J Affect Disord*. 2019;245:28-37. https://doi.org/10.1016/j.jad.2018.10.109
37. Mattes A, Roheger M. Nothing wrong about change: the adequate choice of the dependent variable and design in prediction of cognitive training success. *BMC Med Res Methodol*. 2020;20(1):296. https://doi.org/10.1186/s12874-020-01176-8

38. Steptoe A, Deaton A, Stone AA. Subjective wellbeing, health, and ageing. *Lancet*. 2015;385(9968):640-648. https://doi.org/10.1016/S0140-6736(13)61489-0
39. Stewart KJ, Turner KL, Bacher AC, et al. Are fitness, activity, and fatness associated with health-related quality of life and mood in older persons? *J Cardpulm Rehabil*. 2003;23(2):115-121. https://doi.org/10.1097/00008483-200303000-00009
40. Brett CE, Gow AJ, Corley J, Pattie A, Starr JM, Deary IJ. Psychosocial factors and health as determinants of quality of life in community-dwelling older adults. *Qual Life Res*. 2012;21(3):505-516. https://doi.org/10.1007/s11136-011-9951-2
41. Chodosh J, Kado DM, Seeman TE, Karlamangla AS. Depressive symptoms as a predictor of cognitive decline: macarthur studies of successful aging. *Am J Geriatric Psychiatry Official J Am Assoc Geriatric Psychiatry*. 2007;15(5):406-415. https://doi.org/10.1097/01.JGP.0b013e31802c0c63
42. Pusswald G, Tropper E, Kryspin-Exner I, et al. Health-related quality of life in patients with subjective cognitive decline and mild cognitive impairment and its relation to activities of daily living. *J Alzheim Dis JAD*. 2015;47(2):479-486. https://doi.org/10.3233/JAD-150284
43. Sato S, Demura S, Kobayashi H, Nagasawa Y. The relationship and its change with aging between ADL and daily life satisfaction characteristics in independent Japanese elderly living at home. *J Physiological Anthropol Appl Hum Sci*. 2002;21(4):195-204. https://doi.org/10.2114/jpa.21.195
44. Beaudoin M, Desrichard O. Are memory self-efficacy and memory performance related? A meta-analysis. *Psychol Bull*. 2011;137(2):211-241. https://doi.org/10.1037/a0022106
45. O'Shea DM, Dotson VM, Fieo RA, Tsapanou A, Zahodne L, Stern Y. Older adults with poor self-rated memory have less depressive symptoms and better memory performance when perceived self-efficacy is high. *Int J Geriatr Psychiatr*. 2016;31(7):783-790. https://doi.org/10.1002/gps.4392
46. Roheger M, Folkerts A-K, Krohm F, Skoetz N, Kalbe E. Prognostic models for changes in memory performance after memory training in healthy older adults: a systematic review. *Journal of Cognitive Enhancement*. 2020;5(3):1-14. https://doi.org/10.1007/s41465-020-00194-0
47. Roheger M, Folkerts A-K, Krohm F, Skoetz N, Kalbe E. Prognostic factors for change in memory test performance after memory training in healthy older adults: a systematic review and outline of statistical challenges. *Diagnostic Prognostic Res*. 2020;4(1):7. https://doi.org/10.1186/s41512-020-0071-8
48. Salk RH, Hyde JS, Abramson LY. Gender differences in depression in representative national samples: meta-analyses of diagnoses and symptoms. *Psychol Bull*. 2017;143(8):783-822. https://doi.org/10.1037/bul0000102

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