

Supplementary Material

Physical Activity for Cognitive Health: A Model for Intervention Design for People Experiencing Cognitive Concerns and Symptoms of Depression or Anxiety

Supplementary Material 2.

Summary data for behavior change mechanisms of action targeted by included studies

Study	Included physical activity types	Theoretical Framework	Identified change techniques and intervention delivery modes	Key mechanisms of action (from the TaTT)
Reviews, mixed age adults with depression				
Stubbs et al., 2016 [1]	Mixed aerobic and strength	NR	Credible source Instruction on how to perform behavior Monitoring of behaviour without feedback Feedback on behaviour Social support (unspecified) Social support (practical) Restructuring the social environment Restructuring the physical environment	General attitudes/beliefs Attitude towards the behaviour Knowledge Skills Beliefs about capabilities Motivation Feedback processes Social influences Environmental context and resources Behavioural cueing
Stanton et al., 2014 [2]	Aerobic	NR	Credible source Instruction on how to perform behavior Goal setting (behavior) Action planning Feedback on behavior Social support (unspecified) Social support (practical) Restructuring the social environment Social comparison Remove aversive stimulus	General attitudes/beliefs Attitude towards the behaviour Goals Intention Knowledge Skills Beliefs about capabilities Motivation Social influences Environmental context and resources Norms Subjective norms Feedback processes Behavioral cueing
Knapen et al., 2015 [3]	Mixed aerobic, strength and balance	MI & TTM	Credible source Instruction on how to perform behavior Goal setting (behavior) Graded tasks Action planning Behavioral contract Self-monitoring of behavior Feedback on behavior Feedback on outcomes of behavior Biofeedback Review behavior goals Social support (emotional) Problem solving Pros and cons	General attitudes/beliefs Attitude towards the behavior Knowledge Skills Beliefs about capabilities Goals Intentions Behavioral cueing Behavioral regulation Feedback processes Motivation Beliefs about consequences Perceived susceptibility

			<p>Information about health consequences</p> <p>Information about emotional consequences</p> <p>Verbal persuasion about capability</p> <p>Focus on past success</p> <p>Prompts/cues</p> <p>Valued self-identity</p> <p>Reduce negative emotion</p> <p>Re-attribution</p> <p>Framing/reframing</p>	<p>Memory/attention and decision processes</p> <p>Social influences</p> <p>Environmental context and resources</p> <p>Emotion</p>
Belvederi Murri et al., 2018 [4]			<p>Credible source</p> <p>Monitoring of behaviour without feedback</p> <p>Feedback on behaviour</p> <p>Social support unspecified</p> <p>Instruction on how to perform behavior</p> <p>Social comparison</p> <p>Restructuring the social environment</p> <p>Information about emotional consequences</p> <p>Monitoring of emotional consequences</p> <p>Self-monitoring of behavior</p> <p>Self-monitoring outcomes of behavior</p> <p>Goal setting (behavior)</p> <p>Goal setting (outcome)</p>	<p>Knowledge</p> <p>Skills</p> <p>Feedback processes</p> <p>Motivation</p> <p>General attitudes/beliefs</p> <p>Attitude towards the behavior</p> <p>Beliefs about consequences</p> <p>Beliefs about capabilities</p> <p>Behavioral regulation</p> <p>Social influences</p> <p>Goals</p> <p>Intention</p> <p>Norms</p> <p>Subjective norms</p>
Machaczek et al., 2018 [5]	Aerobic	Coleman's model	<p>Credible source</p> <p>Instruction on performing behavior</p> <p>Goal setting (behavior)</p> <p>Problem solving</p> <p>Information about health consequences</p> <p>Information about emotional consequences</p> <p>Information about social and environmental consequences</p> <p>Information about antecedents</p> <p>Action planning</p> <p>Social support (unspecified)</p> <p>Monitoring of behavior without feedback</p> <p>Feedback</p> <p>Reduce negative emotions</p> <p>Framing/re-framing</p> <p>Restructuring the social environment</p> <p>Restructuring the physical environment</p> <p>Credible source</p> <p>Verbal persuasion about capabilities</p>	<p>Knowledge</p> <p>Skills</p> <p>Attitude towards the behavior</p> <p>General attitudes/beliefs</p> <p>Intention</p> <p>Goals</p> <p>Beliefs about capabilities</p> <p>Beliefs about consequences</p> <p>Behavioral regulation</p> <p>Perceived susceptibility/vulnerability</p> <p>Social influences</p> <p>Norms</p> <p>Subjective norms</p> <p>Environmental context and resources</p> <p>Emotions</p> <p>Memory, attention and decision processes</p> <p>Motivation</p> <p>Behavioral cueing</p>
Schuch et al., 2019 [6]	Aerobic		<p>Social support (unspecified)</p> <p>Goal setting (behavior)</p> <p>Goal setting (outcome)</p> <p>Graded tasks</p> <p>Credible source</p> <p>Instruction on performing behavior</p> <p>Framing/reframing</p>	<p>Beliefs about capabilities</p> <p>Beliefs about consequences</p> <p>Environmental context and resources</p> <p>Intentions</p> <p>Goals</p> <p>Motivation</p> <p>General attitudes/behaviors</p> <p>Social influences</p> <p>Behavioral regulation</p> <p>Attitude towards the behavior</p> <p>General attitudes</p> <p>Knowledge</p>

				Skills
Reviews, middle-aged and older adults with anxiety				
Chong et al., 2022 [7]	Mixed aerobic, strength, balance	NR	Credible source Self-monitoring of behavior Feedback on behaviour Social support (unspecified) Instruction on how to perform behavior Social comparison Restructuring the social environment Graded tasks Goal setting (behavior)	Attitude towards the behavior General attitudes/beliefs Behavioral regulation Feedback processes Motivation Social influences Knowledge Skills Beliefs about capabilities Norms Subjective norms Beliefs about consequences Environmental context and resources Goals Intentions
Primary studies, older adults with depression				
Kerse et al., 2010 [8]	Aerobic, strength, balance	NR	Goal setting (outcome) Goal setting (behavior) Instruction on how to perform behavior Credible source Social support (practical) Restructuring the social environment Graded tasks Self-monitoring of behavior Problem solving Feedback (behavior)	Intentions Goals Motivation Knowledge Skills Beliefs about capabilities Attitude toward the behavior General attitudes/beliefs Social influences Environmental context and resources Behavioral regulation Feedback processes Subjective norms
Belvederi Murri et al., 2015 [9]	Aerobic Strength	NR	Credible source Instruction on how to perform behavior Feedback on behavior Biofeedback Goal setting (behavior) Social support (unspecified) Social comparison Restructuring the social environment Review behavior goals Graded tasks	Knowledge Skills General attitudes/beliefs Attitude towards the behavior Motivation Feedback processes Beliefs about capabilities Intentions Goals Social influences Norms Subjective norms Behavioral regulation
Pfaff et al., 2014 [10]	Aerobic and strength	NR	Goal setting (behavior) Instruction on how to perform behavior Adding objects to the environment Graded tasks Self-monitoring of behavior Feedback on behavior Review behavior goals Social support (unspecified)	Intentions Goals Knowledge Skills Beliefs about capabilities Beliefs about consequences Behavioral regulation Motivation Feedback processes Social influences Environmental context and resources

				Behavioral cueing
Primary studies, mixed age adults with depression				
Callaghan et al., 2011 [11]		TTM	Credible source Instruction on how to perform the behavior Information about health consequences Information about antecedents Pros and cons Incompatible beliefs Verbal persuasion about capability Goal setting (behavior) Goal setting (outcome) Social support (unspecified) Social comparison Restructuring the social environment Graded tasks Problem solving Self-monitoring the behavior Restructuring the social environment	Attitudes towards the behavior General attitudes/beliefs Social influences Knowledge Skills Environmental context and resources Skills Beliefs about capabilities Beliefs about consequences Motivation Intentions Goals Perceived susceptibility/vulnerability Social influences Norms Subjective norms Behavioral regulation Feedback processes
Trivedi et al., 2011 [12]	Aerobic	NR	Credible source Instruction on performing behavior Goal-setting (behavior) Self-monitoring of behavior Feedback on behavior Feedback on outcomes of behavior Biofeedback Problem solving Graded tasks Commitment Social support (practical) Action planning Prompts/cues	Attitude towards the behavior General attitudes/beliefs Knowledge Skills Beliefs about capabilities Intentions Goals Behavioral regulation Feedback processes Motivation Social influences Environmental context and resources Behavioral cueing Memory, attention and decision processes
Carneiro et al., 2015 [13]	Aerobic	NR	Credible source Goal setting (behavior) Instruction on how to perform behavior Feedback on behaviour Self-monitoring of behavior Biofeedback Social support (unspecified) Social support (emotional) Social support (practical) Social comparison Restructuring the physical environment Graded tasks Non-specific reward Generalization of target behavior	Attitude towards the behaviour General attitudes/beliefs Intentions Goals Knowledge Skills Beliefs about capabilities Behavioral regulation Feedback processes Motivation Social influences Environmental context and resources Norms Subjective norms Behavioral cueing Reinforcement
Danielsson et al., 2014 [14]	Mixed aerobic	NR	Credible source Goal setting (behavior)	Attitude towards the behavior General attitudes/beliefs

	and strength		<p>Instruction on how to perform the behaviour</p> <p>Action planning</p> <p>Biofeedback</p> <p>Feedback on behaviour</p> <p>Adding objects to the environment</p> <p>Social support (unspecified)</p> <p>Social comparison</p>	<p>Goals</p> <p>Intentions</p> <p>Knowledge</p> <p>Skills</p> <p>Beliefs about capabilities</p> <p>Behavioral cueing</p> <p>Motivation</p> <p>Feedback processes</p> <p>Social influences</p> <p>Norms</p> <p>Subjective norms</p> <p>Environmental context and resources</p>
Uebelacker et al., 2017 [15]	Yoga	NR	<p>Credible source</p> <p>Instruction on how to perform behavior</p> <p>Social support (unspecified)</p> <p>Social comparison</p> <p>Restructuring the social environment</p> <p>Goal setting (behaviour)</p> <p>Adding objects to the environment</p> <p>Generalization of target behavior</p>	<p>Attitude towards the behavior</p> <p>General attitudes/beliefs</p> <p>Knowledge</p> <p>Skills</p> <p>Beliefs about capabilities</p> <p>Social influences</p> <p>Norms</p> <p>Subjective norms</p> <p>Environmental context and resources</p> <p>Goals</p> <p>Intentions</p>
Kerling et al., 2015 [16]	Aerobic	NR	<p>Credible source</p> <p>Instruction on how to perform the behavior</p> <p>Goal setting (behavior)</p> <p>Restructuring the physical environment</p> <p>Restructuring the social environment</p> <p>Social support (unspecified)</p> <p>Biofeedback</p> <p>Feedback on behavior</p> <p>Graded tasks</p>	<p>Attitude towards the behavior</p> <p>General attitudes/beliefs</p> <p>Knowledge</p> <p>Skills</p> <p>Beliefs about capabilities</p> <p>Goals</p> <p>Intentions</p> <p>Environmental context and resources</p> <p>Behavioral cueing</p> <p>Feedback processes</p> <p>Motivation</p>
Gujral et al., 2019 [17]	Aerobic	NR	<p>Credible source</p> <p>Instruction on how to perform behavior</p> <p>Feedback on behavior</p> <p>Biofeedback</p> <p>Social support (unspecified)</p> <p>Goal setting (behavior)</p>	<p>Attitude towards the behavior</p> <p>General attitudes/beliefs</p> <p>Knowledge</p> <p>Skills</p> <p>Beliefs about capabilities</p> <p>Motivation</p> <p>Feedback processes</p> <p>Social influences</p> <p>Goals</p> <p>Intentions</p>
Soucy et al., 2017 [18]	Mixed aerobic and strength	NR	<p>Information about health consequences</p> <p>Information about emotional consequences</p> <p>Goal setting (behavior)</p> <p>Goal setting (outcome)</p> <p>Self-monitoring of behavior</p> <p>Goal review</p> <p>Problem solving</p>	<p>Knowledge</p> <p>Beliefs about consequences</p> <p>Attitudes towards the behavior</p> <p>Perceived susceptibility/vulnerability</p> <p>Goals</p> <p>Intentions</p> <p>Motivation</p> <p>Behavioral regulation</p> <p>Feedback processes</p> <p>Beliefs about capabilities</p>

Mota-Pereira et al., 2011 [19]	Aerobic	NR	<p>Credible source</p> <p>Instruction on how to perform behavior</p> <p>Social support (unspecified)</p> <p>Goal setting (behavior)</p> <p>Information about antecedents</p> <p>Prompts/cues</p> <p>Biofeedback</p> <p>Feedback on behavior</p> <p>Generalization of target behavior</p>	<p>Attitude towards the behavior</p> <p>General attitudes/beliefs</p> <p>Knowledge</p> <p>Skills</p> <p>Beliefs about capabilities</p> <p>Social influences</p> <p>Goals</p> <p>Intentions</p> <p>Behavioral regulation</p> <p>Memory, attention and decision processes</p> <p>Environmental context and resources</p> <p>Behavioral cueing</p> <p>Feedback processes</p> <p>Motivation</p>
Chalder et al., 2012 [20]	Aerobic	SDT	<p>Credible source</p> <p>Goal setting (behavior)</p> <p>Instruction on performing the behavior</p> <p>Social support (unspecified)</p> <p>Social support (practical)</p> <p>Goal review</p> <p>Problem solving</p> <p>Verbal persuasion about capability</p>	<p>Attitudes toward the behavior</p> <p>General attitudes/beliefs</p> <p>Goals</p> <p>Intentions</p> <p>Knowledge</p> <p>Skills</p> <p>Beliefs about capabilities</p> <p>Social influences</p> <p>Environmental context and resources</p> <p>Behavioral regulation</p>
Szuhany and Otto, 2020 [21]	Aerobic and stretching	NR	<p>Credible source</p> <p>Information about emotional consequences</p> <p>Information about health consequences</p> <p>Goal setting (behavior)</p> <p>Instruction on performing behavior</p> <p>Action planning</p> <p>Self-monitoring of behavior</p> <p>Feedback on behavior</p> <p>Social support (unspecified)</p> <p>Goal review</p>	<p>Attitude to the behavior</p> <p>General attitudes/beliefs</p> <p>Knowledge</p> <p>Beliefs about consequences</p> <p>Intentions</p> <p>Perceived susceptibility/vulnerability</p> <p>Goals</p> <p>Skills</p> <p>Beliefs about capabilities</p> <p>Behavioral cueing</p> <p>Behavioral regulation</p> <p>Feedback processes</p> <p>Motivation</p> <p>Social influences</p>
Doose et al., 2015 [22]	Aerobic	NR	<p>Credible Source</p> <p>Goal setting (behavior)</p> <p>Instruction on how to perform behavior</p> <p>Social support (unspecified)</p> <p>Social comparison</p> <p>Self-monitoring of behavior</p>	<p>Attitude towards the behavior</p> <p>General attitudes/beliefs</p> <p>Goals</p> <p>Intentions</p> <p>Knowledge</p> <p>Skills</p> <p>Beliefs about capabilities</p> <p>Social influences</p> <p>Norms</p> <p>Subjective norms</p> <p>Feedback processes</p> <p>Behavioral regulation</p>
La Rocque et al., 2021 [23]	Bikram yoga	NR	<p>Credible source</p> <p>Information about health consequences</p> <p>Instruction on performing behavior</p> <p>Goal setting (behavior)</p>	<p>Attitude towards the behavior</p> <p>General attitudes/beliefs</p> <p>Knowledge</p> <p>Beliefs about consequences</p>

			Social support (unspecified) Social comparison Self-monitoring of behavior Restructuring the physical environment	Intentions Skills Beliefs about capabilities Goals Social influences Norms Subjective norms Feedback processes Behavioral regulation Environmental context and resources
Primary studies, mixed age adults with anxiety				
Gordon et al., 2020 [24]	Strength	NR	Credible source Instruction on performing behavior Feedback on behavior Social support (unspecified) Adding objects to the environment Graded tasks	Attitude towards the behavior General attitudes/beliefs Knowledge Skills Beliefs about capabilities Feedback processes Motivation Social influences Environmental context and resources

Change techniques identified in existing review papers or intervention reports for PA interventions for adjacent populations, and linked MoAs according to The Theory and Techniques Tool.

TaTT, Theory and Techniques Tool; NR, nil reported; MI, motivational interviewing; TTM, transtheoretical model of change; SDT, self-determination theory.

REFERENCES

- [1] Stubbs B, Vancampfort D, Rosenbaum S, Ward PB, Richards J, Soundy A, Veronese N, Solmi M, Schuch FB (2016) Dropout from exercise randomized controlled trials among people with depression: A meta-analysis and meta regression. *J Affect Disord* **190**, 457-466.
- [2] Stanton R, Reaburn P (2014) Exercise and the treatment of depression: a review of the exercise program variables. *J Sci Med Sport* **17**, 177-182.
- [3] Knapen J, Vancampfort D, Moriën Y, Marchal Y (2015) Exercise therapy improves both mental and physical health in patients with major depression. *Disabil Rehabil* **37**, 1490-1495.
- [4] Belvederi Murri M, Ekkekakis P, Menchetti M, Neviani F, Trevisani F, Tedeschi S, Latessa PM, Nerozzi E, Ermini G, Zocchi D, Squatrito S, Toni G, Cabassi A, Neri M, Zanetidou S, Amore M (2018) Physical exercise for late-life depression: Effects on symptom dimensions and time course. *J Affect Disord* **230**, 65-70.
- [5] Machaczek KK, Allmark P, Goyder E, Grant G, Ricketts T, Pollard N, Booth A, Harrop D, de-la Haye S, Collins K, Green G (2018) A scoping study of interventions to increase the uptake of physical activity (PA) amongst individuals with mild-to-moderate depression (MMD). *BMC Public Health* **18**, 392.
- [6] Schuch FB, Stubbs B (2019) The role of exercise in preventing and treating depression. *Curr Sports Med Rep* **18**, 299-304.

- [7] Chong TWH, Kootar S, Wilding H, Berriman S, Curran E, Cox KL, Bahar-Fuchs A, Peters R, Anstey KJ, Bryant C, Lautenschlager NT (2022) Exercise interventions to reduce anxiety in mid-life and late-life anxiety disorders and subthreshold anxiety disorder: a systematic review. *Ther Adv Psychopharmacol* **12**, 20451253221104958.
- [8] Kerse N, Hayman KJ, Moyes SA, Peri K, Robinson E, Dowell A, Kolt GS, Elley CR, Hatcher S, Kiata L, Wiles J, Keeling S, Parsons J, Arroll B (2010) Home-based activity program for older people with depressive symptoms: DeLLITE--a randomized controlled trial. *Ann Fam Med* **8**, 214-223.
- [9] Belvederi Murri M, Amore M, Menchetti M, Toni G, Neviani F, Cerri M, Rocchi MB, Zocchi D, Bagnoli L, Tam E, Buffa A, Ferrara S, Neri M, Alexopoulos GS, Zanetidou S (2015) Physical exercise for late-life major depression. *Br J Psychiatry* **207**, 235-242.
- [10] Pfaff JJ, Alfonso H, Newton RU, Sim M, Flicker L, Almeida OP (2014) ACTIVEDEP: a randomised, controlled trial of a home-based exercise intervention to alleviate depression in middle-aged and older adults. *Br J Sports Med* **48**, 226-232.
- [11] Callaghan P, Khalil E, Morres I, Carter T (2011) Pragmatic randomised controlled trial of preferred intensity exercise in women living with depression. *BMC Public Health* **11**, 465.
- [12] Trivedi MH, Greer TL, Church TS, Carmody TJ, Grannemann BD, Galper DI, Dunn AL, Earnest CP, Sunderajan P, Henley SS, Blair SN (2011) Exercise as an augmentation treatment for nonremitted major depressive disorder: a randomized, parallel dose comparison. *J Clin Psychiatry* **72**, 677-684.
- [13] Carneiro LS, Fonseca AM, Vieira-Coelho MA, Mota MP, Vasconcelos-Raposo J (2015) Effects of structured exercise and pharmacotherapy vs. pharmacotherapy for adults with depressive symptoms: A randomized clinical trial. *J Psychiatr Res* **71**, 48-55.
- [14] Danielsson L, Papoulias I, Petersson EL, Carlsson J, Waern M (2014) Exercise or basic body awareness therapy as add-on treatment for major depression: a controlled study. *J Affect Disord* **168**, 98-106.
- [15] Uebelacker LA, Kraines M, Broughton MK, Tremont G, Gillette LT, Epstein-Lubow G, Abrantes AM, Battle C, Miller IW (2017) Perceptions of hatha yoga amongst persistently depressed individuals enrolled in a trial of yoga for depression. *Complement Ther Med* **34**, 149-155.
- [16] Kerling A, Tegtbur U, Gützlaff E, Kück M, Borchert L, Ates Z, von Bohlen A, Frieling H, Hüper K, Hartung D, Schweiger U, Kahl KG (2015) Effects of adjunctive exercise on physiological and psychological parameters in depression: a randomized pilot trial. *J Affect Disord* **177**, 1-6.
- [17] Gujral S, Aizenstein H, Reynolds CF, 3rd, Butters MA, Grove G, Karp JF, Erickson KI (2019) Exercise for depression: a feasibility trial exploring neural mechanisms. *Am J Geriatr Psychiatry* **27**, 611-616.
- [18] Soucy I, Provencher M, Fortier M, McFadden T (2017) Efficacy of guided self-help behavioural activation and physical activity for depression: a randomized controlled trial. *Cogn Behav Ther* **46**, 493-506.
- [19] Mota-Pereira J, Silverio J, Carvalho S, Ribeiro JC, Fonte D, Ramos J (2011) Moderate exercise improves depression parameters in treatment-resistant patients with major depressive disorder. *J Psychiatr Res* **45**, 1005-1011.

- [20] Chalder M, Wiles NJ, Campbell J, Hollinghurst SP, Haase AM, Taylor AH, Fox KR, Costelloe C, Searle A, Baxter H, Winder R, Wright C, Turner KM, Calnan M, Lawlor DA, Peters TJ, Sharp DJ, Montgomery AA, Lewis G (2012) Facilitated physical activity as a treatment for depressed adults: randomised controlled trial. *BMJ* **344**, e2758.
- [21] Szuhany KL, Otto MW (2020) Efficacy evaluation of exercise as an augmentation strategy to brief behavioral activation treatment for depression: a randomized pilot trial. *Cogn Behav Ther* **49**, 228-241.
- [22] Doose M, Ziegenbein M, Hoos O, Reim D, Stengert W, Hoffer N, Vogel C, Ziert Y, Sieberer M (2015) Self-selected intensity exercise in the treatment of major depression: A pragmatic RCT. *Int J Psychiatry Clin Pract* **19**, 266-275.
- [23] La Rocque CL, Mazurka R, Stuckless TJR, Pyke K, Harkness KL (2021) Randomized controlled trial of bikram yoga and aerobic exercise for depression in women: Efficacy and stress-based mechanisms. *J Affect Disord* **280**, 457-466.
- [24] Gordon BR, McDowell CP, Lyons M, Herring MP (2020) Resistance exercise training for anxiety and worry symptoms among young adults: a randomized controlled trial. *Sci Rep* **10**, 17548.