Available online at www.sciencedirect.com

ScienceDirect

Current Opinion in Behavioral Sciences

Enhancing attention through training

Michael I Posner[1], Mary K Rothbart[1] and Yi-Yuan Tang[2]

Attention can be improved by repetition of a specific task that involves an attention network (network training), or by exercise or meditation that changes the brain state (state training). We first review the concept of attention networks that link changes in orienting, alerting and executive control to brain networks. Network training through video games or computer exercises can improve aspects of attention. The extent of transfer beyond the trained task is a controversial issue. Mindfulness is a form of meditation that keeps attention focused on the current moment. Some forms of meditation have been shown to improve executive attention reduce stress and produce specific brain changes. Additional research is needed to understand the limits and mechanisms of these effects.

Addresses
[1] University of Oregon, United States
[2] Texas Tech University, United States

Corresponding author: Posner, Michael I (mposner@uoregon.edu)

Current Opinion in Behavioral Sciences 2015, **4**:1–5

This review comes from a themed issue on **Cognitive enhancement**

Edited by **Barbara Sahakian** and **Arthur Kramer**

http://dx.doi.org/10.1016/j.cobeha.2014.12.008

Introduction

We consider two brain training strategies to improve attention and other cognitive functions [1••]. Network training involves practice of a cognitive task thought to exercise specific brain networks related to attention. State training, on the other hand, uses practice designed to develop a brain state that may influence attention and other networks [2–6]. State training also involves networks, but it is does not include cognitive tasks designed specifically to train a network. Both aerobic exercise and meditation training can establish a state that appears to improve cognition, attention and mood [1••].

Training attention networks

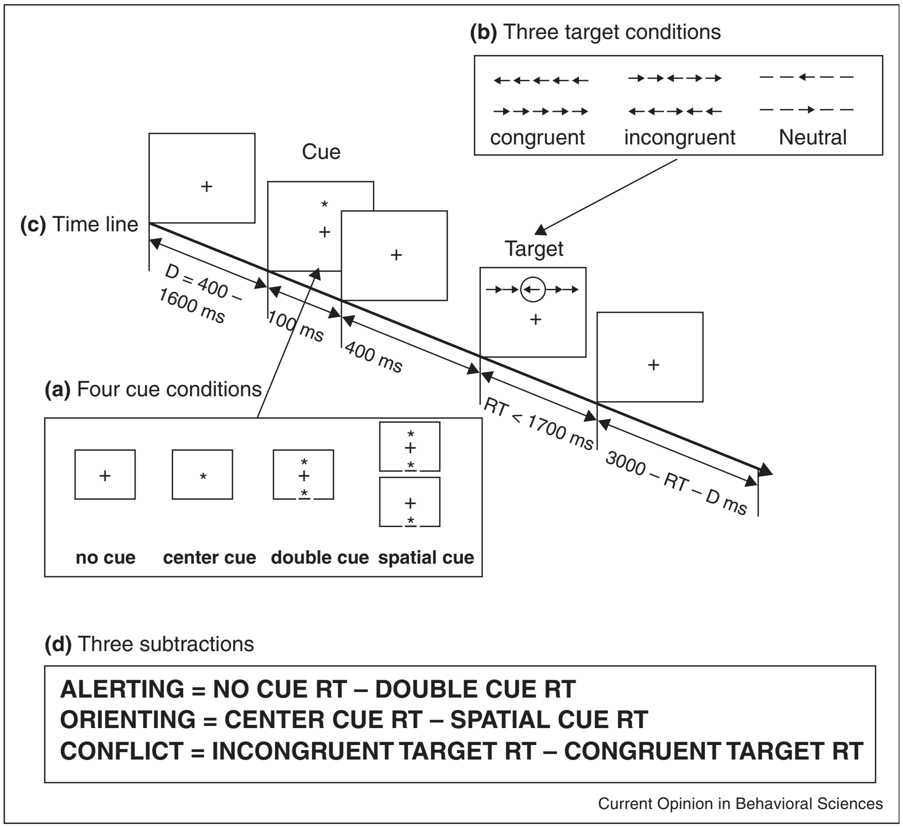
Since attention involves a number of neural networks with different functions [7] there are many ways to improve one or more of these functions and thereby improve the efficiency of the network. Some of the cues for dissociations between attentional functions arise from studies of brain injury using the Attention Network Test (ANT) to classify patients. The ANT (see Fig. 1) is a cognitive task built around the flanker effect and designed to provide separate measurement of the alerting, orienting and executive networks [8]. Limitations in the reliability and utility of the ANT, especially for applied research, have been discussed [9]. While some efforts have been made to improve the test its main goal is to link behavioral changes in attention to the brain networks involved.

For example, in one study 110 stroke patients and 62 control participants were given the ANT [10]. Analysis of brain scans and ANT revealed three separate groups of patients: (i) those patients with thalamic damage showing deficits in alerting, (ii) parietal damage patients showing deficits in orienting, and (iii) patients with damage to white matter tracts connected to the anterior cingulate showing deficits in executive control [10]. This classification into three categories fits with many findings from imaging research summarized in Ref. [7].

Studies have used training techniques to improve attention in patient groups similar to those discussed above. Patients with thalamic damage and participants who are sleep deprived have trouble in obtaining a sufficient level of alertness to perform well in cognitive tasks. The use of auditory warning signals has been shown to provide a temporary improvement in performance and training to use the signals can improve both alerting and orienting functions [11]. Patients with right parietal damage often have problems orienting to signals that go directly to the damaged hemisphere. Training involving teaching the patients to instruct themselves to orient to the left during visual search improved performance [12]. Training in action video games has been shown to improve orienting network performance during visual search and similar tasks [13]. There is more doubt that general improvement in all forms of attention or learning occurs with videogame training [14,15••]. However, in a recent very extensive training study with video games and controls the authors do find that transfer to untrained paradigms in some forms of video games [15]. A similar controversy regarding transfer is found when training involves a specific but general network such as working memory [16,17].

Many studies of training executive attention have been carried out in children [18••,19,20] using computerized exercises designed to improve conflict resolution [19,20] or more general school curricula designed to exercise all aspects of executive functions [18••]. These studies have often demonstrated in improvement executive attention [18••] and some transfer [19,20]. While there is evidence

Figure 1



A schema of the Attention Network Test. **(a)** Cue conditions, **(b)** target conditions, **(c)** time line of events. Adapted from Ref. [8].

that self control score in childhood can predict adult performance [21] there are no studies showing that training the executive network in children can improve adult outcomes. Although most of the work in video games has been done with adults and most of the work on school curricula with children there is little evidence that training is limited to any one age.

There may be ways to enhance the success of network training. For example, there is evidence that training parents can greatly enhance the effectiveness of child training, presumably by getting the parent to support home activity [22]. It is also possible that brain stimulation through scalp electrodes or trans-cortical magnetic stimulation (TMS) may improve plasticity and enhance training [23]. The safety of the stimulation methods, particularly when practiced by consumers without training, remains an important concern [24]. Below we consider some state training methods that can be used either individually or in combination with network training.

Training brain states

A number of methods have been proposed for training a brain state that will foster attention and self regulation [1••]. Exposure to nature has been shown to be a useful method to improve attention [1••], and aerobic exercise has been shown in many studies to have broad effects on cognition including attention [6]. Meditation is a mental method that has the most similarities to the network training discussed above. In understanding the training of attention it is important to consider the way attention works during cognitive tasks.

When involved in cognitive tasks it is common for the human mind to wander to thoughts unrelated to the task [25] and mind wandering is often directed to the self [26]. In some cases there is awareness of the mind wandering and in other cases one is not aware until questioned. To determine the occurrence of such thinking it is valuable to employ experience sampling [27] where participants are probed to report whether or not their mind is wandering. In one such study participants carried out a sustained attention task [28] while being scanned with fMRI and probed as to whether their mind had wandered and whether they had been aware of that wandering. Findings suggest that both the default (a mostly midline network of brain areas showing correlated activity when the person is not engaged in a task) and executive networks are active during mind wandering [29]. The activation in both networks is greater when the person is not aware of mind wandering prior to the probe. Meditation is a method that works to resist mind wandering and produce an attention focus.

Five different styles of meditation have been involved in over 400 clinical trials [30], but one style of meditation, mindfulness meditation seems to dominant current studies. Mindfulness meditation involves a set of mental practices designed to achieve control by the person over the direction of attention. This is done by either focusing on a specific content (e.g. ones breathing or a word) or keeping a relaxed state in which attention is not allowed to move away from the present state but is not focused on a particular content. Recent meta-analyses of the behavioral effects of meditation [31], functional brain systems involved [32,33] and structural changes in brain gray and white matter [34•] have been generally favorable to changes in behavior induced by various forms of meditation training.

The meditative state is often accompanied by changes in measures related to autonomic activity often used as a biomarker for monitoring meditative states [31,32]. The central nervous system also undergoes changes following meditation training. Consistent structural changes found in a metaanalysis [34•] are in the ACC and insula parts of the executive attention network [7].

Many of the early meditation studies compared long time practitioners with control participants selected to be similar to the meditators. Although many findings were of interest, it was hard to be sure that differences were due to meditation rather than to other differences between those devoted to the practice and controls. More recently longitudinal studies over periods of a week to several months have compared training with various forms of meditation to either waiting list or other controls. These studies allow random assignment and can attribute cause to the training. The studies have often found important differences attributed to meditation [2–5,32,33,34•,35–37]. However, meditation training is itself complex and it remains unclear which aspects of the training are most important to obtain each of the changes discussed below.

Longitudinal studies

A series of meditation training studies have compared one week of integrated body mind training (IBMT), a version of mindfulness meditation, with an active control group given relaxation training [3,37,38] The groups are randomly assigned. IBMT uses most of the methods of other mindfulness training including maintaining attention in the present without judgment and use of instruction to promote a state of high concentration on the present with minimal mind wandering. Relaxation training involves deliberate relaxation of each muscle group and has been widely practiced as a part of cognitive behavioral therapy. In comparison with the relaxation control group, one week of IBMT (30 min per day) produced better executive attention using the Attention Network Test, higher positive mood and lower negative mood in self report, lower secretion of the stress hormone cortisol following meditation after a mental arithmetic challenge and increased immuno-reactivity [3].

A month of IBMT in comparison with a relaxation training control group showed reduced cortisol at baseline (before any cognitive stress) and evidence that stress was reduced in a dose dependent manner. These changes do not seem to be dependent upon specific aspects of IBMT as they have been reported with other mindfulness methods [39]. However, one well documented form of training, mindfulness based stress reduction [40] has not been found to improve attention [41]. The reasons for this difference are not known.

The IBMT studies also examined both central and autonomic nervous system activity in comparison to relaxation controls. There was clear evidence of changes in activity in the ventral ACC and in its functional connectivity with the striatum [37,38]. These findings fit well with meta-analysis of meditation effects on functional and structural activation [4]. In addition two to four weeks of IBMT produced increases in fractional anisotropy (FA), an index of white matter efficiency [38]. These changes were found in a band of white matter tracts connecting the ACC to striatal and cortical areas. After two weeks, the changes were mainly in axial diffusivity (AD), often taken as a measure of axonal density, while after four weeks the study found both improved AD and improved RD (radial diffusivity, related to myelination) [38].

White matter is usually regarded as changing in development, but relatively fixed in adulthood. However, recent reviews have shown much more dynamism in adult white matter that can be changed rapidly in response to events such as demyelination in conjunction with multiple sclerosis [42•].

A number of studies of network training have also found changes in white matter with practice [43–45,46••]. The finding of an early change in AD followed later by RD is similar to the order of changes found in early development and raises the question of whether examination of behavioral changes that occur with learning in adults may provide added insight into the slower changes manifest during child development [38]. It is only possible to speculate on exactly how meditation and other forms of learning might work to alter white matter, but a recent paper points to frontal theta as a possible important cause of these effects [47].

Clinical studies

Many physical and mental disorders involve deficits of attention [48], so an important goal of training attention is to treat disorders. There are correlations between the executive attention network and self control or self regulation in children and adults [49•]. Since addictions have been related to deficits in self regulation [50] they are a natural target for such studies.

One such study has involved smoking addiction [51••], but unlike most such studies participants were not committed to quit smoking, but were recruited for stress reduction. Smokers and non smokers were randomly assigned to two weeks of IBMT or two weeks of relaxation training. The IBMT group showed a 60% reduction in smoking as measured by a carbon monoxide meter, while the control group showed no significant reduction. Prior to training smokers showed lower activity in the anterior cingulate than non smokers, but the training produced an increase in ACC activation. The authors suggest that self regulation was reduced in smokers prior to training, but increased after IBMT training. Although there is increased interest in using training methods to improve several clinical conditions [48,49•], research will be needed to understand more fully how this can best be brought about.

Future issues

Training brain networks and changing brain states have both proven effective in some studies as a means of improving attention. For network training, the degree of transfer to remote tasks remains an important issue. The claims that training in a single task improves vast areas of cognition seems to be unjustified. However, effort to train a set of tasks that might together make a more general improvement in attention and cognition remains a possibility.

State training does not involve a single task so the issue of how general the effects are is rather different than for network training. Some forms of meditation have been shown to improve attention [3,37], but others may not. For state training there are remaining issues about which methods are most effective, their mechanisms and how long they last following training. Executive attention appears to be important in achieving ability for self control. State training through meditation has been used to reduce addiction by increasing self regulation. Other disorders involving attention may also be improved by training, but more research on this is needed.

Conflict of interest statement

Nothing declared.

Acknowledgements

This research was supported by the Office of Naval Research grant to the University of Oregon and by the National Institute of Health grant HD060563 to Georgia State University.

References

1. •• Tang YY, Posner MI: **Attention training and attention state training**. *Trends Cogn Sci* 2009, **13**:222-227.
This paper classifies attention training methods into those designed to alter particular brain networks and those designed to change brain state.

2. Tang YY, Rothbart MK, Posner MI: **Neural correlates of establishing, maintaining and switching brain states**. *Trends Cogn Sci* 2012, **16**:330-337.

3. Tang YY, Ma Y, Wang J, Fan Y, Feng S, Lu Q, Yu D, Rothbart MK, Fan M, Posner MI: **Short-term meditation training improves attention and self regulation**. *Proc Natl Acad Sci U S A* 2007, **104**:17152-17156.

4. Holzel BK, Lazar SK, Gard T, Schuman-Olivier Z, Vago DR, Ott U: **How does mindfulness meditation work? Proposing mechanisms of action from a conceptual and neural perspective**. *Perspect Psychol Sci* 2011, **6**:537-559.

5. Tang YY, Posner MI, Rothbart MK: **Meditation improves self-regulation over the life span**. *Ann N Y Acad Sci* 2014, **1307**:104-111.

6. Hillman CH, Erickson KI, Kramer AF: **Be smart, exercise your heart: exercise effects on brain and cognition**. *Nat Rev Neurosci* 2008, **9**:58-65.

7. Petersen SE, Posner MI: **The attention system of the human brain: 20 years after**. *Ann Rev Neurosci* 2012, **35**:71-89.

8. Fan J, McCandliss BD, Sommer T, Raz A, Posner MI: **Testing the efficiency and independence of attentional networks**. *J Cognit Neurosci* 2002, **3**:340-347.

9. Redick TS, Engle RW: **Working memory capacity and attention network test performance**. *Appl Cognit Psychol* 2006, **20**:713-721.

10. Rinne P, Hassan M, Goniotakis D, Chohan K, Sharma P, Langdon D, Soto D, Bentley P: **Triple dissociation of attention networks in stroke according to lesion location**. *Neurology* 2013, **81**:812-820.

11. Thimm M, Fink GR, Küst J, Karbe H, Sturm W: **Impact of alertness training on spatial neglect: a behavioural and fMRI study**. *Neuropsychology* 2006, **44**:1230-1246.

12. Van Kessel ME, Geurts ACH, Brouwer WH, Fasotti L: **Visual scanning training for neglect after stroke with and without a computerized lane tracking dual task**. *Front Hum Neurosci* 2013, **7**:358.

13. Green CS, Bavelier D: **Action video games modify visual selective attention**. *Nature* 2003, **423**:534-537.

14. Boot WR, Kramer AF, Simons DJ, Fabiani M, Gratton G: **The effects of video game playing on attention, memory, and executive control**. *Acta Psychol* 2008, **129**:387-398.

15. •• Baniqued P, Kranz MB, Voss MW, Lee H, Casman JD, Severson J, Kramer AF: **Cognitive training with casual video games: points to consider**. *Front Psychol* 2014, **4** Article 1010.
Extensive treatment of the cognitive effects of video game training.

16. Redick TS, Shipstead Z, Harrison TL, Fried DE, Hamrick DZ, Kane MJ, Engle RW: **No evidence of intelligence improvement after working memory training: a randomized, placebo-controlled study**. *J Exp Psychol General* 2013, **142**:359-379.

17. Harrison TL, Shipstead Z, Hicks KL, Hambrick DZ, Redick TS, Engle RW: **Working memory training may increase working memory capacity but not fluid intelligence**. *Psychol Sci* 2013, **24**:2409-2419.

18. •• Diamond A, Lee K: **Interventions shown to aid executive function development in children 4–12 years old**. *Science* 2011, **333**:959-964.
An overview of methods of training attention and executive function in children.

19. Rueda MR, Rothbart MK, McCandliss B, Saccamanno L, Posner MI: **Training, maturation and genetic influences on the development of executive attention**. *Proc Natl Acad Sci U S A* 2005, **102**:14931-14936.

20. Rueda MR, Checa P, Combita LM: **Enhanced efficiency of the executive attention network after training in preschool children: immediate and after two month effects**. *Dev Cognit Neurosci* 2012, **2(Supplement 1)**:S192-S204.

21. Moffitt TE, Arseneault L, Belsky D, Dickson N, Hancox RJ, Harrington HL, Houts R, Poulton R, Roberts BW, Ross S, Sears MR, Thomson WM, Caspi A: **A gradient of childhood self-control predicts health, wealth and public safety**. *Proc Natl Acad Sci U S A* 2011, **108**:72693-72698.

22. Neville HJ, Stevens C, Pakulak E, Bell TA, Fanning J, Klein S, Isbell E: **Family-based training program improves brain function, cognition, and behavior in lower socioeconomic status preschoolers**. *Proc Natl Acad Sci U S A* 2013, **110**: 12138-12143.

23. Utz KS, Dimova V, Oppenländer K, Kerkhoff G: **Electrified minds: transcranial direct current stimulation (tDCS) and Galvanic Vestibular Stimulation (GVS) as methods of non-invasive brain stimulation in neuropsychology—a review of current data and future implications**. *Neuropsychology* 2010, **48**:2789-2810.

24. Kadosh RC, Levy N, O'Shea J, Shea N, Savulescu J: **The neuroethics of noninvasive brain stimulation**. *Curr Biol* 2012, **22**:R108-R111.

25. Smallwood J, Schooler JW: **The restless mind**. *Psychol Bull* 2006, **132**:946-958.

26. Epernay M: *The McLandress Dimension*. New York: Houghton Mifflin; 1963, .

27. Kahneman D, Krueger AB, Schkade DA, Schwarz N, Stone AA: **A survey method for characterizing daily life experience: the day reconstruction method**. *Science* 2004, **306**:1776-1780.

28. Robertson IH, Manly T, Andrade J, Baddeley BT, Yend J: **Oops! Performance correlates of everyday attention failure in traumatic brain injured and normal subjects**. *Neuropsychology* 1997, **35**:747-758.

29. Christoff K, Gordon AM, Smallwood J, Schooler JW: **Experience sampling during fMRI reveals default network and executive system network contributions to mind wandering**. *Proc Natl Acad Sci U S A* 2009, **106**:8719-8724.

30. Ospina MB, Bond K, Karkhaneh M, Buscemi N, Dryden DM, Barnes V, Carlson LE, Dusek JA, Shannahoff-Khalsa D: **Clinical trials of meditation practices in health care: characteristics and quality**. *J Altern Complement Med* 2008, **14**:1199-1213.

31. Sedlmeier P, Eberth J, Schwarz M, Zimmermann D, Haarig F, Jaeger S, Kunz S: **The psychological effects of meditation: a meta-analysis**. *Psychol Bull* 2012, **138**:1139-1171.

32. Cahn BR, Polich J: **Meditation states and traits. EEG, ERP and neuroimaging studies**. *Psychol Bull* 2008, **132**:180-211.

33. Vago DA, Silbersweig DA: **Self awareness, self regulation and self transcendence (S-ART): a framework for understanding the neurobiological mechanisms of mindfulness**. *Front Hum Neurosci* 2012, **6**:1-30.

34. • Fox KCR, Nijrboer S, Dixon ML, Floman JL, Ellamil M, Rumak SP, Sedlmeier P, Christoff K: **Is meditation associated with altered brain structure? A systematic review and meta-analysis of morphometric neuroimaging in meditation practitioners**. *Neurosci Biobehav Rev* 2014, **43**:48-73.
This study examines evidence for structural changes due to meditation.

35. Tomasino B, Fregona S, Skrap M, Fabbro F: **Meditation-related activations are modulated by the practices needed to obtain it and by the expertise: an ALE meta-analysis study**. *Front Hum Neurosci* 2013, **6**:346.

36. Lutz A, Slagter HA, Dunne JD, Davidson RJ: **Attention regulation and monitoring in meditation**. *Trends Cognit Sci* 2008, **12**: 163-169.

37. Tang YY, Ma Y, Fan Y, Feng H, Wang J, Feng S, Lu Q, Hu B, Lin Y, Li J, Zhang Y, Wang Y, Zhou L, Fan M: **Central and autonomic nervous system interaction is altered by short term meditation**. *Proc Natl Acad Sci U S A* 2009, **106**:8865-8870.

38. Tang YY, Lu Q, Fan M, Yang Y, Posner MI: **Mechanisms of white matter changes induced by meditation**. *Proc Natl Acad Sci U S A* 2012, **109**:10570-10574.

39. Allen M, Dietz M, Blair KS, van Beek M, Rees G, Vestergaard-Poulsen P, Lutz A, Roepstorff A: **Cognitive-affective neural plasticity following active controlled mindfulness intervention**. *J Neurosci* 2012, **32**:15601-15610.

40. MacCoon DG, MacLean KA, Davidson RJ, Saron CD, Lutz A: **No sustained attention differences in a longitudinal randomized trial comparing mindfulness based stress reduction versus active control**. *PLOS ONE* 2014, **9**:e97551.

41. MacCoon DG, Imel ZE, Rosenkranz MA, Sheftel JG, Weng HY, Sullivan JC, Bonus KA, Stoney CM, Salomons TV, Davidson RJ, Lutz A: **The validation of an active control intervention for Mindfulness Based Stress Reduction (MBSR)**. *Behav Res Ther* 2012, **50**:3.

42. • Beirowski B: **Concepts for regulation of axon integrity by enwrapping glia**. *Front Cell Neurosci* 2013, **7**:256.
An important paper showing the dynamic nature of changes in white matter in adults under some circumstances.

43. Takeuchi H, Sekiguchi A, Taki Y, Yokoyama S, Yomogida Y, Komuro N, Yamanouchi T, Suzuki S, Kawashima R: **Training of working memory impacts structural connectivity**. *J Neurosci* 2010, **30**:3297-3303.

44. Bengtsson SL, Nagy Z, Skare S, Forsman L, Forssberg H, Ullen F: **Extensive piano practicing has regionally specific effects on white matter development**. *Nat Neurosci* 2005, **8**:1148-1150.

45. Hu YZ, Geng FJ, Tao L, Hu N, Du FL, Fu KA, Chen FY: **Enhanced white. Matter tracts integrity in children with abacus training**. *Hum Brain Map* 2011, **32**:10-21.

46. •• Zatorre RJ, Fields RD, Johansen-Berg H: **Plasticity in gray and white: neuroimaging changes in brain structure during learning**. *Nat Neurosci* 2012, **15**:528-536.
An excellent review of white matter changes due to learning.

47. Posner MI, Tang YY, Lynch G: **Mechanisms of white matter change induced by meditation training**. *Front Psychol* 2014, **5** Article 1220.

48. Tang YY, Posner MI, Rothbart MK: **Meditation improves self-regulation over the life span. In advances in meditation research: neuroscience and clinical applications**. *N Y Acad Sci* 2014, **1307**:104-111.

49. • Rothbart MK, Rueda MR: **The development of effortful control**. In *Developing Attention in the Human Brain: A Tribute to Michael I. Posner 2005.* Edited by Mayr U, Awh E, Keele SW. Washington, DC: American Psychological Association; 2005:167-188.

50. Volkow ND, Baler R: **Addiction: a disease of self control in neurosciences and the human person: new perspectives of human activities**. *Pontif Acad Sci Scr Varia* 2013, **121**:1-6.

51. •• Tang Y, Tang R, Posner MI: **Brief meditation training induces smoking reduction**. *Proc Natl Acad Sci U S A* 2013, **110**: 13971-13975.
Evidence that a brief training period can reduce smoking even when there is no intention on the part of the participant to do so.