

Inhibitory Control Training (ICT) Reduces The Consumption of Nicotine Among Young, Healthy Female Smokers

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Research Article

Keywords: executive control, response inhibition, inhibitory control training, ICT, smoking, smoking cessation

Posted Date: June 24th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-613700/v1>

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Abstract

Inhibitory control training (ICT) proved to be effective in the reduction of unhealthy food or alcohol consumption, but its efficacy in smoking reduction is hard to estimate due to the scarcity of relevant research. In our randomized controlled trial, the participants (N = 84) were recruited from the population of young healthy female smokers who were motivated to quit. The experimental group underwent an ICT procedure based on the Go/No Go paradigm. The predetermined stop signals ('no go' condition) were associated mostly with smoking-related pictures (90% consistency), whereas the response signals were associated with matched neutral pictures. There were two active control groups: the first had an equal proportion of neutral and smoking-related pictures in the 'go' and 'no go' trials; the second trained inhibitory control according to the same scheme as the experimental group, but the participants were not exposed to any smoking-related cues. All groups underwent 13 training sessions over 25 days. All participants completed a battery of questionnaires and cognitive tasks three times: before training, after its completion, and two months later. We found that all participants reduced the feeling of craving and devalued the smoking-related pictures. Since there were no between-group differences, these effects probably did not result from ICT. However, we found that the experimental group smoked significantly less cigarettes than the control groups; they also reduced the number of smoking days during the preceding 30-day period. The results suggest that extensive ICT training may serve as an effective method of reducing nicotine intake.

Introduction

In spite of anti-tobacco campaigns, smoking is still a serious problem for public health policy. In Poland, the 2017 national survey [1] revealed that about 24% of people older than 15 years reported smoking every day. Although women smoke less frequently than men (20% vs. 29%, respectively), smoking is an increasing problem in the younger female population. Additionally, women more frequently than men reported that they had started to smoke in the previous 12 months. At the same time, 41% of nicotine-addicted women declared the intention to quit smoking, in comparison to only 17% of male nicotine users [1]. It is therefore important to develop effective procedures that might be helpful for smokers who intend to cease nicotine intake. In this paper we focus on a behavioural procedure called inhibitory control training (ICT).

ICT is a procedure based on the 'go/no-go' (GNG) paradigm, which is widely used in research on executive control [2–3]. In GNG tasks, people are supposed to respond as quickly as possible to a predefined 'go' signal (e.g., a square) and to refrain from responding if a predefined 'stop' signal occurs (e.g., a diamond). A small number of faulty responses in 'no-go' trials and short reaction times in 'go' trials are indicators of the efficiency of prepotent response inhibition, which is understood as one of the basic dimensions of executive control [4] and self-control [5]. In ICT, the 'go' and 'no-go' signals are usually combined with specially selected visual cues that are associated with eating, drinking alcohol, or smoking cigarettes. For instance, squares that serve as the predefined 'no-go' signals may be associated with visual stimuli related to smoking, whereas circles that serve as 'go' signals may be accompanied by neutral stimuli [6].

Participants are not explicitly asked to refrain from pressing keys in response to stimuli related to eating, drinking, or smoking; however, when they are instructed to do nothing in trials in which an arbitrary 'no-go' signal appears on the screen, they supposedly learn to associate response inhibition with unhealthy consumption thanks to the consistency between 'no-go' signals and consumption-related stimuli. Such a procedure has proved effective in reducing the quantity of unhealthy snacks consumed by preschool children [7]. Similar results have been obtained with adults [8–9], although there are caveats concerning the reportedly short duration of training effects [10]. Also, the effects of training are sometimes observable only in laboratory settings and do not transfer to real-life dietary behaviour [11]. The ICT procedure has also been used with success in attempts to reduce the amount of alcohol consumed [11–13].

As for nicotine dependence, it has been found that smokers' inhibitory control is impaired in comparison to non-smokers [14, 15]; hence, ICT training seems advisable in their case. However, empirical evidence is too scarce to allow conclusive remarks. Adams and her colleagues [6] obtained results suggesting that ICT may improve participants' smoking resistance, i.e., their ability to delay the gratification afforded by smoking a cigarette. However, the number of smoked cigarettes was not reduced thanks to training, and the general efficiency of inhibitory control did not change either. Moreover, their study was based on a single training session that took about 30 minutes, therefore a bigger training dose might produce more convincing results. In the study reported by Bos and co-workers [16], participants were asked to practise every day for a two-week period, but the results were disappointing since all participants reduced their tobacco consumption, including the active control group. So, we do not know whether ICT works with tobacco users or, if it does, what the cognitive underpinnings of its possible effectiveness are. There are at least two possibilities: (1) ICT improves the overall efficiency of inhibitory control and (2) ICT decreases the affective value of stimuli associated with tobacco smoking, similarly to the well-known phenomenon of evaluative conditioning [17–18]. If the first mechanism is dominant, the effects of training, if existent at all, should generalize on inhibitory control tasks that were not used during the training sessions. The second mechanism does not predict such transfer effects, but it should make the smoking-related stimuli less pleasant for participants who are asked to judge their value [19].

In this study, we investigated young female smokers because tobacco use in this group is increasing in spite of frequently declared intentions to quit. Also, women tend to smoke for different reasons than men [20], so the gender homogeneity of the sample seemed important to us. Next, we designed two active control groups, which is a solution rarely practiced in the cognitive training research. The experimental group practised 'go' trials mostly with neutral stimuli and 'no-go' trials mostly with smoking-related pictures. The first control group had an equal proportion of neutral and smoking-related stimuli in both 'go' and 'no-go' trials. The second experimental group had only neutral stimuli which were divided into 'go' and 'no-go' trials according to their spatial orientation. Thanks to such a design, the potential effects of training should be possible to explain in terms of the specificity of the ICT procedure rather than in terms of a non-specific placebo-like mechanism. Additionally, in order to assess potential transfer effects, we used a battery of cognitive measures, including an inhibitory control task that was different from the

practised one. Finally, we arranged the follow-up measurement of results, which took place two months after the completion of training.

Method

Ethical statement

The study has been performed according to the Declaration of Helsinki. All subjects gave written informed consent and were informed that they had the right to withdraw at any moment. Ethical approval of the study was issued by the Committee for Ethics of Scientific Research, Institute of Psychology, Jagiellonian University in Kraków. Date: Oct. 3, 2016, Code: KE/06/102016.

Design

The study was arranged according to the 3x3 mixed factorial design, with one between-subject factor of group (experimental, active control 1, active control 2) and one within-subject factor of time (pre-test, post-test, follow-up).

Participants

The required number of participants has been calculated with the *G*Power 3.1* calculator [21]. Assuming the power value $(1-\beta) = 0.95$, the significance level $\alpha = 0.05$, the small effect size = 0.2, and taking into account the 3x3 mixed factorial design, we needed 81 participants. However, training studies tend to suffer from unexpected drop-outs, so we recruited 100 participants. After quick resignation of two persons, the experiment started with 98 smoking women; 14 of them dropped out at various stages of the procedure. In consequence, we gathered complete data from 84 participants (mean age = 23.36, SD = 3.15), who were recruited via ads placed on websites and via the mailing systems of local higher-education institutions. Volunteers were required to be smokers older than 18 and younger than 33, who were not nicotine dependent and wanted to quit smoking. Participants were compensated with 150 PLN (about €35) at the end of the entire study.

Materials

Questionnaires and surveys. We used a battery of self-report instruments that allowed assessment of nicotine dependence, nicotine consumption, craving, motivation to quit smoking, some personality dimensions that seemed relevant in the context of smoking, and subjectively experienced mood.

FTND. The Polish version [22] of the Fagerström Test of Nicotine Dependence [23] consists of six questions that refer to smoking habits. Exemplary items are '*How soon after waking up do you smoke your first cigarette?*' or '*Do you find it difficult to refrain from smoking in places where it is forbidden? E.g., library, church, etc.*'. Since this questionnaire measures nicotine dependence level, it helped us to screen out volunteers who did not meet the study participation criteria (see the procedure section).

Schneider Motivation Test. We used this tool in order to evaluate participants' motivation to quit smoking. The Polish version [22] contains 12 questions such as *'Do you want to quit smoking?'* or *'Have you ever tried to quit smoking before?'*. This instrument also served as a screening tool (see the procedure section).

QSU-Brief. The Tiffany Questionnaire for Smoking Urges – Brief [24] consists of 10 questions concerning the desire to smoke a cigarette. It is a measure of momentary nicotine craving. These are exemplary items: *'Nothing would be better than smoking a cigarette right now'* or *'I could control things better if I could smoke right now'*. The QSU-Brief scores served as one of the dependent variables used to estimate the effects of training (see the Results section).

IVE. This personality scale is also called Eysenck's Impulsivity Inventory [25]. In its Polish adaptation [26] it consists of 54 questions with 'yes' or 'no' answers. The results are summed up to three subscales: Impulsiveness, Venturesomeness, and Empathy. Since impulsiveness and preference for risky behaviour are personality dimensions that predict smoking [27], we treated the IVE subscales as potential moderators of possible training effects.

Mood, state anxiety, stress. In order to assess participants' mood, we administered the Polish adaptation [28] of the UWIST Mood Adjective Check List UMACL [29], which consists of 29 adjectives related to three dimensions of subjectively experienced mood: Hedonic Tone, Tense Arousal, and Energetic Arousal. We also used X-1 subscale from the Polish adaptation [30] of the State Trait Anxiety Inventory for Adults STAI [31], which consists of 20 questions that refer to anxiety as a momentarily perceived mental state. Finally, the Perceived Stress Scale (PSS 10), developed by Cohen, Kamarck, and Mermelstein [32] and adapted by Juczyński and Ogińska-Bulik [33], consists of 10 questions about subjective feelings related to personal problems and coping strategies. Mood, state anxiety, and stress were assessed in order to check whether they would depend on training regimes. Moreover, we intended to check whether potential training effects would be moderated by the subjective feelings typically associated with smoking cigarettes. So, the scores from UMACL, STAI, and PSS 10 were treated either as dependent variables or as covariates in the general linear model of data analysis.

Cigarette consumption (TLFB). Participants were asked to self-report their cigarette consumption through the timeline follow-back procedure (TLFB), originally developed for alcohol dependence studies [34]. TLFB was administered in Polish via an Excel sheet downloaded from Nova Southeastern University page (<https://www.nova.edu/gsc/forms/timeline-followback-forms.html>). We asked participants to recall how many cigarettes they had smoked each day in the previous 30 days; instructions were provided to make these recollections easier. This method allows data to be gathered on the total number of cigarettes smoked in the previous 30 days and the number of days (in the 30-day period) on which a participant smoked. We used these data as dependent variables in the analysis of the effectiveness of the ICT training (see the Results section).

Tasks. Apart from surveys and questionnaires, we employed two executive control tasks (Go/No-Go and Stop-signal) and a task designed to evaluate visual stimuli that were either neutral or associated with

smoking (Visual Analogue Scales, VAS).

Go/No-Go test. In order to check training effects (pre-test, post-test, follow-up), we used the Go/No-Go task from the Millisecond Test Library [35–36]. At the beginning of each trial, the participants were presented with a blank rectangle which was oriented vertically (90% probability of a ‘go’ trial) or horizontally (90% probability of a ‘no-go’ trial). Then, the colour of the rectangle changed to orange or purple after various durations of SOA (100, 200, 300, 400, 500 ms). Participants were asked to respond with the spacebar to one of these colours (‘go’) and refrain from responding when another colour appeared (‘no-go’). The connection between colours and the required mode of behaviour (‘go’ vs. ‘no go’) was counterbalanced across participants. Half of the overall number of trials belonged to the ‘go’ condition, and the other half were the ‘no-go’ trials.

Go/No-Go training. In the training, a cue-specific GNG task was used. At the beginning of each trial, a picture with a white frame appeared on the screen. Next, the frame became blue or grey. Depending on the counterbalanced instructions, participants were asked to press the spacebar if the specified colour of frame occurred (‘go’) and refrain from responding if another colour was present (‘no-go’). The pictures within the frame were selected from the International Smoking Image Series [37]. They showed either objects associated with smoking (e.g., a person holding a cigarette) or carefully matched neutral objects (e.g., a person holding a ballpoint pen). In the experimental group, 90% of no-go trials contained smoking-related pictures and 10% of such trials included non-smoking-related pictures. Consequently, 10% of no-go trials contained no-smoking pictures and 90% contained pictures related to smoking. In the active control group 1, the proportion of smoking-related and non-smoking-related pictures in ‘no-go’ and ‘go’ trials was equal (50%). In the active control group 2, 90% of ‘no-go’ trials had left-oriented neutral pictures and 10% of such trials had right-oriented pictures that were also neutral. In the ‘go’ trials, this proportion was reversed.

The rationale for such a design of the GNG task was as follows. Firstly, we wondered if the 100% consistency between smoking-related pictures and the ‘no go’ condition that was adopted in other studies [6] would make the task too easy and therefore susceptible to quick automatization. Leaving a margin of uncertainty in the form of the 10% probability that the ‘go’ conditions would coincide with smoking-related pictures should make the participants more alert and focused. This problem seemed important because our participants were required to do the training version of the GNG task as frequently as 13 times over consecutive 25 days. Making the task more demanding should prevent participants from lapses of attention. Secondly, an equal proportion of neutral and smoking-related pictures in the ‘go’ and ‘no go’ conditions (control group 1) was chosen in order to prevent participants forming associations between smoking and ‘go’ trials. If we had just reversed the proportion between the experimental and control groups, we might have encouraged the control group to smoke, which would both unethical and methodologically flawed. Such solutions are also practised by other researchers [6, 12, 38]. Thirdly, the 90/10 proportion of ‘go’ and ‘no go’ trials that depended on the spatial orientation of pictures rather than on their content (control group 2) was chosen in order to check whether the ICT training, if effective at all, works through the general improvement of inhibitory control (compare: 38–39). Active control group 2,

similarly to the experimental group, was supposed to practise cognitive inhibition according to the same scheme. The only difference amounted to the content of stimuli, which were domain specific (smoking-related) in the experimental group and neutral (not related to smoking at all) in control group 2.

Stop Signal Task. We administered the Stop Signal Task [40], available from the Millisecond Test Library [36] and modified by Verbruggen and co-workers [41]. At the beginning of each trial, participants were presented with an empty circle. Next, in the centre of this circle a white arrow appeared which could be directed either to the right or to the left. Participants were asked to press the D key if the arrow was left oriented or the K key if the arrow was right oriented; however, they were instructed to withhold their reaction when the acoustic stop signal (beep) sounded after presentation of the arrow. The delay between the visual stimuli and the acoustic stop signal was initially 250ms and was then adjusted up or down (by 50ms) depending on the participant's performance. The proportion of trials with and without the stop signal was 1:3. The stop signal reaction time (time between the stop signal and the unobservable mental reaction to it) was calculated according to the following rationale: the latency of the internal response to the stop signal must be equal to the mean reaction time in 'go' responses due to the 0.50 probability of responding in trials with the stop signal. In turn, this probability is 0.50 as a result of adjustment of the stop signal delay to the accuracy in the previous trial. Hence, stop signal reaction time (SSRT) is calculated as the difference between the mean reaction time and the adjusted Stop Signal Delay (SSD). A low SSRT value indicates that a person is able to inhibit his/her reactions even if the stop signal is relatively late [41]. Therefore, SSRT is an estimation of the strength of inhibitory control.

VAS. Modified Visual Analogue Scales from the Millisecond Test Library [36] served as an assessment tool that allowed the visual stimuli employed in the training version of GNG tasks to be rated as pleasant or unpleasant. Stimuli chosen from the International Smoking Image Series [37] were either smoking-related or neutral; they appeared one by one near the top of the screen, whereas the sliding scale was near the bottom. The left side of the scale was always associated with the word 'unpleasant', whereas the right side was associated with the word 'pleasant'. Participants were instructed to express their subjective feelings about the pictures by clicking with the mouse on the respective point of the sliding scale, which ranged between zero and 100.

Procedure

General procedure. First, volunteers who had responded to the ads were asked to fill in the online screening survey, which contained the Fagerström Test of Nicotine Dependence (FTND) and the Schneider Motivation Test. Participants whose scores from FTND were less than seven (no pharmacological dependence) and who answered positively to more than half of the Schneider Motivation Test items were selected and invited to take part in the main experiment. They also had to be females aged 18 to 33 years who wanted to quit smoking and did not use any nicotine replacement therapy or e-cigarettes; relevant questions concerning these issues were included in the screening survey.

The assessment part of the study took place in The Laboratory of the Experimental Psychology at Jagiellonian University in Krakow. Participants were examined in small groups from two to five people.

They were asked to abstain from smoking cigarettes for 12 hours before the assessment session, which always started in the morning (between 9am and 12pm). Volunteers were first greeted and informed briefly about the experiment. Next, in order to check if they had abstained from smoking, their carbon dioxide level in exhaled air was tested with Smokerlyzer piCO. Volunteers who scored above 10 ppm were excluded from the study. Next, the participants did the GNG and SST tasks. In the former, there was one warm-up block with 20 trials in which reactions were followed by feedback notification, and two regular blocks with 120 trials without feedback. In the SST tasks, there was one warm-up block with 32 trials and three regular blocks with 64 trials; feedback about RT and efficiency were provided after each block. After completion of the computerized cognitive tasks, participants completed computerized versions of the Timeline Follow Back for Cigarette use, the VAS with the stimuli used in training (neutral and smoking-related), and the QSU-Brief. Finally, participants filled in the paper-and-pencil questionnaires: IVE, UMACL, PSS10 and STAI. At the end of this meeting, they were instructed how to install the training procedure on their personal computers and how to run it.

The day after completion of training, participants arrived at the laboratory in order to accomplish the same tests and questionnaires as during the first meeting (except IVE). Two months later they were invited again for a follow-up session, during which they did all the procedures once more. After completion of all tests and questionnaires, participants were compensated with the financial reward.

Training procedure. Participants were randomly assigned to three groups. The training regime consisted of 13 sessions performed every second day. The training procedures were programmed with Inquisit Web [36]. On the morning of each training day, each participant received a link to the ascribed training task according to the study design (experimental, control 1, control 2). Every training session consisted of one warm-up block with 20 trials, and two regular blocks with 240 trials.

Results

Data analysis

The statistical analyses were conducted using STATISTICA 13 and IBM SPSS Statistics 25.0. In order to examine the efficacy of training, we used the GLM repeated-measures model with one between-subjects factor of group (experimental, control 1, and control 2) and one within-subjects factor of time (pre-test, post-test, and follow-up). In order to test possible moderation effects, we used the same GLM model with covariates, the latter being either the stable personality variables or momentary states such as mood, anxiety, and stress. If the assumption of sphericity was violated, we used the Greenhouse-Geisser adjustment. The dependent variables in successive GLM analyses were (1) inhibitory control, measured with the SST task, (2) rating of neutral or smoking-related stimuli (VAS), (3) cigarette consumption during the last 30 days (TLFB), and (4) craving for cigarettes (QSU- Brief). The GNG scores were not subjected to the aforementioned analyses because of the very low error rate, which brought about skewness of distribution and a huge reduction of variance.

Characteristics of participants

Participants were randomly assigned to three groups, but almost 15% of them did not complete the whole procedure. So, in the first step we checked whether the groups were nonetheless comparable in terms of their characteristics, as measured in the pre-test. We did not find any statistically significant differences between groups concerning age, smoking behaviour, personality characteristics, and cognitive measures. The only exception refers to rating of no-smoking stimuli, which was a bit lower in the experimental group in comparison to the control groups ($M_E = 31.62$, $M_{C1} = 37.63$, $M_{C2} = 43.33$, $F(2,81) = 3.95$, $p = 0.023$).

Stop Signal Task

Stop signal reaction time (SSRT) is a measure of the efficacy of inhibitory control. We did not find any significant effect of time ($F(2,130) = 1.83$, $p = 0.172$, $\eta^2 = 0.02$) or training group ($F(2,81) = 0.11$, $p = 0.899$, $\eta^2 = 0.003$); the interaction was not statistically significant, either ($F(3,130) = 0.27$, $p = 0.898$, $\eta^2 = 0.01$). The planned contrast showed a nonsignificant difference between pre-test and post-test in the experimental group ($t = 1.88$, $p = 0.064$), the active control group 1 ($t = 0.44$, $p = 0.660$), and the active control group 2 ($t = 1.46$, $p = 0.147$). Likewise, there were no differences between pre-test and follow-up (experimental group: $t = 1.17$, $p = 0.246$; active control group: $t = 0.23$, $p = 0.819$ active control group 2: $t = 1.37$, $p = 0.175$). Therefore, the training showed no transfer effects from the GNG task to the SST task, although both procedures are supposed to measure the effectiveness of inhibitory control.

Rating of stimuli

Neutral stimuli obtained slightly lower ratings on the VAS scale in the post-test and follow-up in comparison to the pre-test ($F(2,139) = 3.58$, $p = 0.037$, $\eta^2 = 0.04$). The main effect of group was not significant ($F(2,81) = 0.51$, $p = 0.601$, $\eta^2 = 0.01$). Interaction between time of measurement and training group was statistically significant ($F(3,139) = 3.92$, $p = 0.007$, $\eta^2 = 0.09$), and the planned contrasts revealed that only the active control group 2 showed significant differences between pre-test and post-test ($t = 3.95$, $p < 0.001$), as well as between pre-test and follow-up ($t = 3.39$, $p = 0.001$). Other groups did not show any reduction of the subjective value of the neutral stimuli.

The smoking-related stimuli were judged as less and less pleasant with consecutive measurement sessions; the devaluation effect was particularly strong between the first and the second measurement (pre-test $M = 35.54$, $SE = 2.31$, post-test $M = 26.08$, $SE = 1.92$, follow-up $M = 24.93$, $SE = 1.85$). The main effect of time was quite strong in terms of the effect size ($F(2,123) = 19.84$, $p < 0.001$, $\eta^2 = 0.20$). The planned contrast revealed significant differences between pre-test and post-test in all three groups (experimental: $t = 2.98$, $p = 0.004$; active control 1: $t = 2.01$, $p = 0.048$; active control 2: $t = 3.59$, $p < 0.001$). Differences between pre-test and follow-up were significant only for the experimental group ($t = 3.69$, $p < 0.001$) and the active control group 2 ($t = 3.34$, $p = 0.001$) but not for the active control group 1 ($t = 1.22$, $p = 0.23$). The main effect of group and the time x group interaction effect were not significant ($F(2,81) = 0.37$, $p = 0.69$, $\eta^2 = 0.01$, and $F(3,123) = 1.41$, $p = 0.242$, $\eta^2 = 0.03$, respectively). These findings indicate that the training regimes caused sizeable subjective devaluation of smoking-related stimuli; however, this effect cannot be linked to the ICT procedure because it occurred in both control groups as well.

Cigarette consumption (TLFB)

The TLFB scores revealed that all participants reduced the self-reported number of smoked cigarettes in the last 30 days before measurement. These findings are presented in Table 1. The main effect of time was statistically significant ($F(2,139) = 5.61, p = 0.007, \eta^2 = 0.07$). The main effect of group ($F(2,81) = 0.55, p = 0.580, \eta^2 = 0.01$) and the group x time interaction ($F(3,139) = 0.17, p = 0.938, \eta^2 = 0.004$) were not significant. However, the planned contrasts showed that participants from the experimental group reported significantly lower frequency of smoking in the post-test ($t = 2.85, p = 0.006$) and follow-up ($t = 2.05, p = 0.044$) in comparison to the pre-test; analogical patterns did not occur in control groups (active control 1: $t = 1.87, p = 0.066$ and $t = 1.28, p = 0.205$; active control 2: $t = 1.61, p = 0.11$ and $t = 1.53, p = 0.131$).

Another significant finding based on the TLFB scores relates to the number of days on which participants smoked cigarettes within the 30-day period preceding the measurement. These findings are presented in Fig. 1. First of all, there is a significant main effect of time ($F(2,144) = 8.91, p < 0.001, \eta^2 = 0.10$). In contrast, the main effect of group was insignificant ($F(2, 81) = 0.59, p = 0.558, \eta^2 = 0.01$) and the interaction between time and training group was not significant either ($F(4, 144) = 1.33, p = 0.263, \eta^2 = 0.03$). However, the planned contrast showed that both the difference between pre-test and post-test ($t = 2.62, p = 0.010$) and the difference between pre-test and follow-up ($t = 3.33, p = 0.001$) were significant only for the experimental group who underwent the ICT regime. For active control group 1, the difference between pre-test and post-test was also significant ($t = 2.46, p = 0.016$), but the contrast between measurement 1 and 3 was not ($t = 1.70, p = 0.092$). In active control group 2, the differences between pre-test and post-test ($t = 0.27, p = 0.786$) as well as between pre-test and follow-up ($t = 1.14, p = 0.258$) were not significant. These findings suggest that only the ICT procedure produced the long-lasting effect of smoking reduction that was noticeable even two months after the completion of training.

We also checked whether the smoking reduction effects were correlated with devaluation of smoking-related pictures. Both the number of smoked cigarettes and ratings of smoking-related pictures decreased in consecutive measurement sessions, although the former effect seems ICT-specific and the latter occurred regardless of the training regime. It was therefore interesting to determine whether the extent of these changes was correlated in any way. Table 2 shows the results of the correlational analyses in which the difference scores were used. We computed the differences in smoking consumption between the first and the second measurement sessions, as well as between the first and the third. Analogically, we computed the difference scores concerning picture evaluations separately for neutral and smoking-related stimuli. As we can see, there is a positive significant correlation between the magnitude of change in cigarette consumption (pre-test vs. follow-up) and the extent of devaluation of smoking-related pictures (pre-test vs. post-test, $r = 0.326, p = 0.002$; and pre-test vs. follow-up, $r = 0.463, p < 0.001$). There was no such relationship concerning the neutral pictures. After splitting the sample into three groups, we found that the relationships between the magnitude of devaluation of smoking-related pictures and the extent of smoking reduction were always positive and significant in the experimental group, regardless of the

time of measurement (pre-test vs. post-test or pre-test vs follow-up). In the control groups, these relationships were not always present, and in one case the correlation was unexpectedly negative. If the correlation coefficients were statistically significant within groups, the between-group differences concerning their strength did not surpass the required level of significance. Altogether, the findings shown in Table 2 may suggest that devaluation is at the core of the ICT procedure as a potential causal factor of smoking reduction effects. However, correlational analyses do not allow causal explanations.

Craving (QSU-Brief)

The QSU-Brief scores revealed that all participants felt less need to smoke a cigarette in the second and third measurement in comparison to the pre-test (Fig. 2). The main effect of time was significant and quite sizeable ($F\{2,139\} = 42.35, p < 0.001, \eta^2 = 0.34$). In contrast, the main effect of group and the interaction between group and time were both insignificant ($F\{2,81\} = 0.35, p = 0.703, \eta^2 = 0.01$), and $F\{3,139\} = 0.06, p = 0.987, \eta^2 = 0.002$, respectively). The planned contrast showed that the differences between pre-test and post-test, as well as between pre-test and follow-up, were significant for all training groups (experimental: $t = 4.38, p < 0.001, t = 4.27, p < 0.001$; active control 1: $t = 3.88, p < 0.001, t = 4.20, p < 0.001$; active control 2: $t = 4.45, p < 0.001, t = 4.18, p < 0.001$). Hence, we can conclude that all groups reduced the subjective feeling of craving, regardless of the training regime.

Mood, state anxiety, stress

The results suggest that mood and state anxiety did not depend on training in any way. Both main and interactive effects were statistically insignificant, with p values ranging between 0.208 and 0.989. As for perceived stress, we found that the PSS 10 scores were higher in the first measurement in comparison to the second and third measurement ($F\{2,162\} = 9.35, p < 0.001, \eta^2 = 0.10$), suggesting that the first visit to the lab was relatively more stressful than the subsequent visits. There were no differences between post-test and follow-up in perceived stress.

Moderation effects

We did not find any moderation effects. Neither personality dimensions, as measured with the IVE, nor the temporary states of mood, stress, or anxiety entered in any interaction with the group factor. Therefore, the observed effects of training, if significant, must be linked solely to the ICT procedure.

Discussion

We arranged 13 inhibitory control training sessions (ICT) for young healthy female smokers who were motivated to reduce nicotine consumption. Three groups of participants underwent training based on the Go/No Go (GNG) task. The experimental group learned to associate 'go' trials with non-smoking visual stimuli and 'no go' trials with carefully matched smoking-related pictures (90% consistency). The active control group 1 underwent a very similar procedure, yet the smoking-related and neutral cues were equally probable in the case of 'go' and 'no go' trials (50% consistency). Lastly, the active control group 2

practised the GNG as the experimental group did, but the pictures used in the GNG task were not related to smoking, regardless of the type of trial. We found that all groups of participants reduced their urge to smoke remarkably. Since there were no differences between groups, this effect cannot be interpreted in terms of ICT effectiveness; instead, it looks like a non-specific effect of participation in a smoking-reduction research project. Moreover, all participants devalued pictures related to smoking, which were rated as less pleasant after training than before. Again, this effect was not specific because it occurred in all groups. The only effect related specifically to the ICT procedure was reduction of smoking. Participants from the experimental group smoked less cigarettes after the ICT procedure, which was not the case with the two control groups. Moreover, the number of smoking days noticeably decreased due to the ICT procedure, and this effect was apparent even two months after the completion of training. In the control group 1, we also observed such an effect, but it did not last until the follow-up measurement. We can therefore conclude that the ICT procedure based on the GNG task proved successful as a means of reducing smoking among young healthy women. We also found that the magnitude of devaluation of smoking-related pictures correlated with the extent of smoking reduction.

This is probably the first empirical evidence that the ICT has an effect on the behaviour of smokers rather than on their subjective feelings or preferences. Other studies with the ICT approach brought about interesting results but did not show any behavioural change concerning smoking habits. Two available studies [6, 13] did not report such effects, although the former [6] predicted some reduction of smoking. The lack of behavioural effects may have resulted from the fact that the GNG training used in that study [6] consisted of just one session. In the second case [13], the main objective was to demonstrate the effect of training-related devaluation of smoking cues, which indeed occurred. The authors did not report whether devaluation caused smoking reduction, or whether the degree of devaluation correlated with the number of consumed cigarettes. It seems that smoking habits were not assessed in their study at all. Remarkably, both Adams and co-workers [6] and Scholten and collaborators [13] have reported the training-related craving reduction effect. In our study, we found both the craving reduction and the devaluation effects; however, we were also able to demonstrate slight behavioural change.

Apart from the two aforementioned studies, a third study devoted to smoking and ICT has been published by Bos and colleagues [16]. Their participants practised every day for a two-week period, and it was found that they significantly reduced the number of smoked cigarettes; however, there were no differences between the experimental and the active control group. Therefore, the authors were unable to demonstrate the effectiveness of the ICT procedure as such. The placebo-like effect of sheer participation in the smoking reduction study occurred in our study as well, but it pertained to reduced craving and devaluation of smoking-related stimuli. As for smoking behaviour, we were able to observe a weak but significant reduction of the number of smoked cigarettes and the number of smoking days during the preceding 30-day period. Maybe the difference between our results and Bos and co-workers' [16] findings stems from the hetero/homogeneity of the samples: Bos and colleagues investigated both men and women, whereas we recruited only women. Moreover, Bos's team investigated smokers who consumed at least 10 cigarettes per day, whereas our participants smoked only 5–6 cigarettes per day on average. If

this line of reasoning makes sense, it would suggest that the ICT procedure works mostly in the case of moderate smokers, but this hypothesis needs empirical falsification.

Although our study supports the line of reasoning according to which the ICT procedure may help to reduce smoking, it does not allow a definitive statement concerning the underlying mechanisms of ICT. The hypothesis that ICT improves the general efficiency of response inhibition did not gain any support. It has been demonstrated in other studies that smokers have difficulties with inhibitory control [14-15, 42-43], especially after tobacco cessation [27, 44]. Even a short-term abstinence from nicotine increases both the number of errors in inhibitory control tasks and the over-activation of brain structures implicated in response inhibition, such as the right inferior frontal gyrus [45]. Inefficiency of inhibitory control during abstinence suggest that smoking a cigarette may operate as a self-regulatory mechanism thanks to which smokers temporarily improve their executive functions. It would be therefore reasonable to hypothesize that general improvement of inhibitory control through ICT should result in smoking reduction. Our results do not justify such a hypothesis for two reasons: firstly, the GNG training effects did not generalize on the SST, although both tasks were supposed to involve response inhibition skills; secondly, active control group 2, which underwent the same procedure as the experimental group but without any smoking-related stimuli, did not show any nicotine-reduction effects. Therefore, the ICT effect looks very specific. It is worth emphasizing that our control group 2 did not perform the general-ICT procedure [38], which employs abstract cues only. Neither did they perform the cue-specific ICT, since their GNG tasks did not contain any smoking-related pictures. Active control group 2 practised on the basis of concrete stimuli and the criterion for the 'go' or 'no go' decision was the spatial orientation of pictures. Their training regime can therefore be described as almost identical to the cue-specific ICT prepared for the experimental group, except for the domain-specificity of the stimuli employed. Using the athletics metaphor, our results suggest that if somebody wishes to master the high jump, s/he has to practise exactly the high jump; neither general fitness nor practising the long jump would work.

Another explanatory hypothesis amounts to the devaluation effect. It is claimed [17] that the ICT procedure makes food-related stimuli less preferable, thus leading to the reduction of unhealthy food consumption. Analogical explanations are also present in alcohol dependence studies [13]. As for smoking, the devaluation effect was clearly demonstrated in the study by Scholten and colleagues [19]. They arranged GNG training in which participants were instructed to refrain from responding to smoking-related pictures after a predetermined acoustic signal. Pictures related to smoking became less attractive after the GNG training in the case of both smoking and non-smoking participants, although the latter rated the smoking cues much lower even before training. Remarkably, there was no control condition in their study which would have made it possible to check whether devaluation took place if the proportion of smoking-related and neutral cues was equal in both 'go' and 'no go' trials. Regardless, the devaluation effect was rather strong but the authors did not report any smoking reduction effects. In our study, such an effect was also quite sizeable, but it was accompanied by an observable reduction in nicotine intake. Still, we cannot claim that devaluation of smoking-related stimuli accounts for the fact that participants smoked less frequently and smoked less cigarettes. In our study, devaluation occurred in all groups regardless of the training regime, therefore it must be treated as a non-specific, placebo-like effect of

sheer participation in the smoking reduction study. If devaluation of smoking-related cues caused smoking cessation or reduction, it should be considered worthwhile training, but for now it seems unable to elicit any real behavioural change. The findings shown in Table 2 indicate that the magnitude of devaluation correlates with the degree of smoking reduction, particularly in the experimental group. These findings may suggest some causal influences, but this is only a correlational approach that does not allow definite conclusions.

We also cannot claim that participants in our experimental group decreased their nicotine intake due to the reduction of the momentary urge to smoke (craving). The craving-reduction effect occurred in all groups, so there is no rationale to interpret it as being caused by the ICT procedure. It is worth noting that craving was also reduced in Scholten et al.'s [19]. The fact that ICT is able to reduce craving is a rather interesting and replicative finding. As an unpleasant subjective feeling, craving may be worth reducing as such, regardless of its questionable influence on smoking cessation or reduction. This kind of training effect probably improves smokers' quality of life but not necessarily their willingness or ability to refrain from smoking a cigarette.

Our study seems inconclusive in reference to the problem of the cognitive underpinnings of the ICT procedure. We did not find any support for two the hypotheses: (1) improvement of the general inhibitory control skill and (2) reduction of craving. The third hypothesis, which links smoking reduction with devaluation of smoking-related stimuli, may seem provisionally acceptable in the light of the correlational data. Importantly, we found support for the main hypothesis of our study that the ICT procedure based on the GNG tasks is effective in the reduction of smoking, although the mechanisms of such effectiveness are still unclear and must be explored in further research.

The conclusions of our study are limited in several ways. Firstly, data from the TLFB procedure that allowed to detect the smoking-reduction effect were based on self-reports. Although TLFB is a reliable procedure that allows quite objective assessment of substance consumption and provides helpful hints to monitor one's consumption patterns, it nevertheless depends on the participants' willingness to report honestly how many cigarettes they smoked on each of the preceding 30 days. Had we applied objective methods, our conclusions might be stronger, although there are numerous technical limitations in the attempts to assess the amount of substance intake more objectively.

Secondly, the smoking-reduction effects were relatively small in terms of the variance explained in comparison to other significant effects that we found, such as the devaluation and craving-reduction effects. It seems that, as far as smoking reduction is concerned, the ICT can bring about quite weak effects. The results pertaining to devaluation or craving are more sizeable and easier to obtain even after a single session of training [6, 19]. However, the question arises of whether these effects would be worthwhile at all if not accompanied by smoking reduction. As a matter of fact, behavioural changes rather than subjective feelings are considered the final goal of cognitive training procedures. If reduced craving or devaluation can help to quit smoking, they would be worthwhile; otherwise, their practical

significance seems questionable, with the possible exception of craving reduction, which probably improves subjective well-being.

Thirdly, our study may be underpowered due to relatively small number of participants (28 in each group). A meta-analysis [11] revealed that, in the studies on food or alcohol intake reduction, the ICT procedure produced effect sizes ranging between zero and 0.61 (mean SMD = 0.36), depending on the particular study, the type of problem (food or alcohol) and the kind of cognitive task used in ICT (stop-signal, go-no go, or anti-saccade). In order to obtain at least moderate effect size in our study, we would need to recruit more participants. However, it was hard to judge the expected value of effect size taking into account the scarcity of relevant studies pertaining to the reduction nicotine intake. Moreover, the above-mentioned meta-analysis [11] is based on 18 effect sizes in total, only four of which were found in the samples larger than ours. In nine reviewed studies the samples were smaller than ours. Although we wished to increase the sample size and eliminate drop-outs, it seems that our study does not deviate from others in terms of the number of participants. It is also worth mentioning that three assessment episodes in the repeated measure schedule allows to strengthen the conclusions. Finally, our sample size was estimated with the G*Power calculator. Still, the problem of statistical power is a real one.

Finally, our study was limited to women who were not heavy smokers. Their reported mean number of consumed cigarettes per day in the pre-test rarely exceeded 10; on average, they consumed 5–6 cigarettes per day. So, this study needs replication with samples of participants that represent people who smoke heavily.

Declarations

Data

The data are accessible through:

<https://datadryad.org/stash/share/KevPzRuGyhZAfXjYr8GDmbsU1kl0Jz95IP2x85ahrsU>

Conflicts of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

CRedit author statement

Edward Necka: Conceptualization, Methodology, Formal analysis, Writing – Original Draft, Writing – Review and Editing, Supervision, Funding acquisition. **Patrycja Naskręt:** Conceptualization, Methodology, Software, Validation, Formal Analysis, Investigation, Resources, Data Curation, Writing – Original Draft, Visualization, Project Administration.

Funding

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Tables

Table 1
Mean total number of smoked cigarettes in the 30 days preceding the measurement

	Pre-test	Post-test	Follow-up
Experimental	M = 165.64 SD = 134.72	M = 125.96 SD = 118.22	M = 127.29 SD = 130.40
Active control 1	M = 159.50 SD = 125.72	M = 133.54 SD = 121.97	M = 135.61 SD = 143.99
Active control 2	M = 188.46 SD = 133.34	M = 166.04 SD = 175.87	M = 159.89 SD = 135.36

Due to technical limitations, table 2 is only available as a download in the Supplemental Files section.

Figures

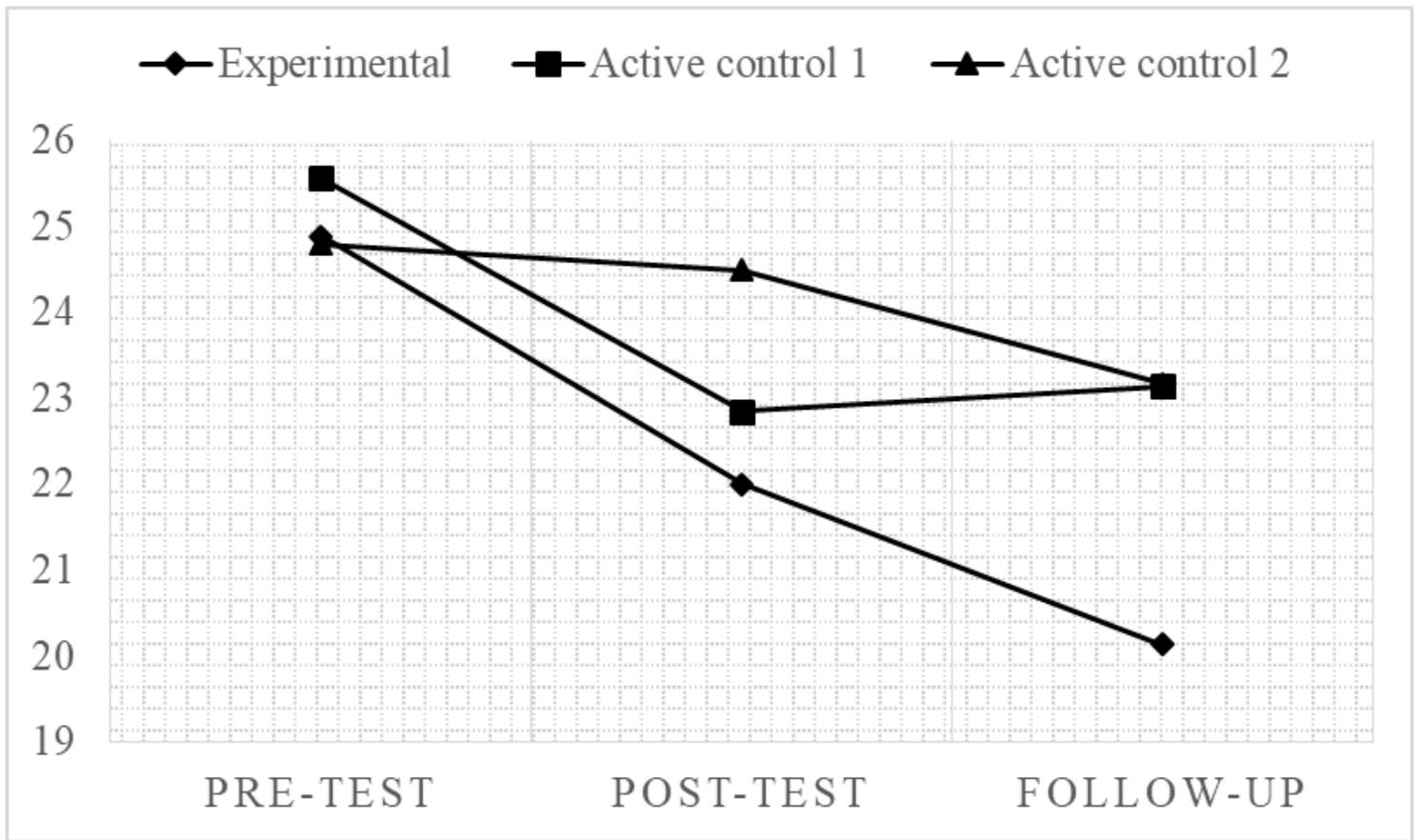


Figure 1

The mean number of days on which participants smoked cigarettes during the last 30-day period.

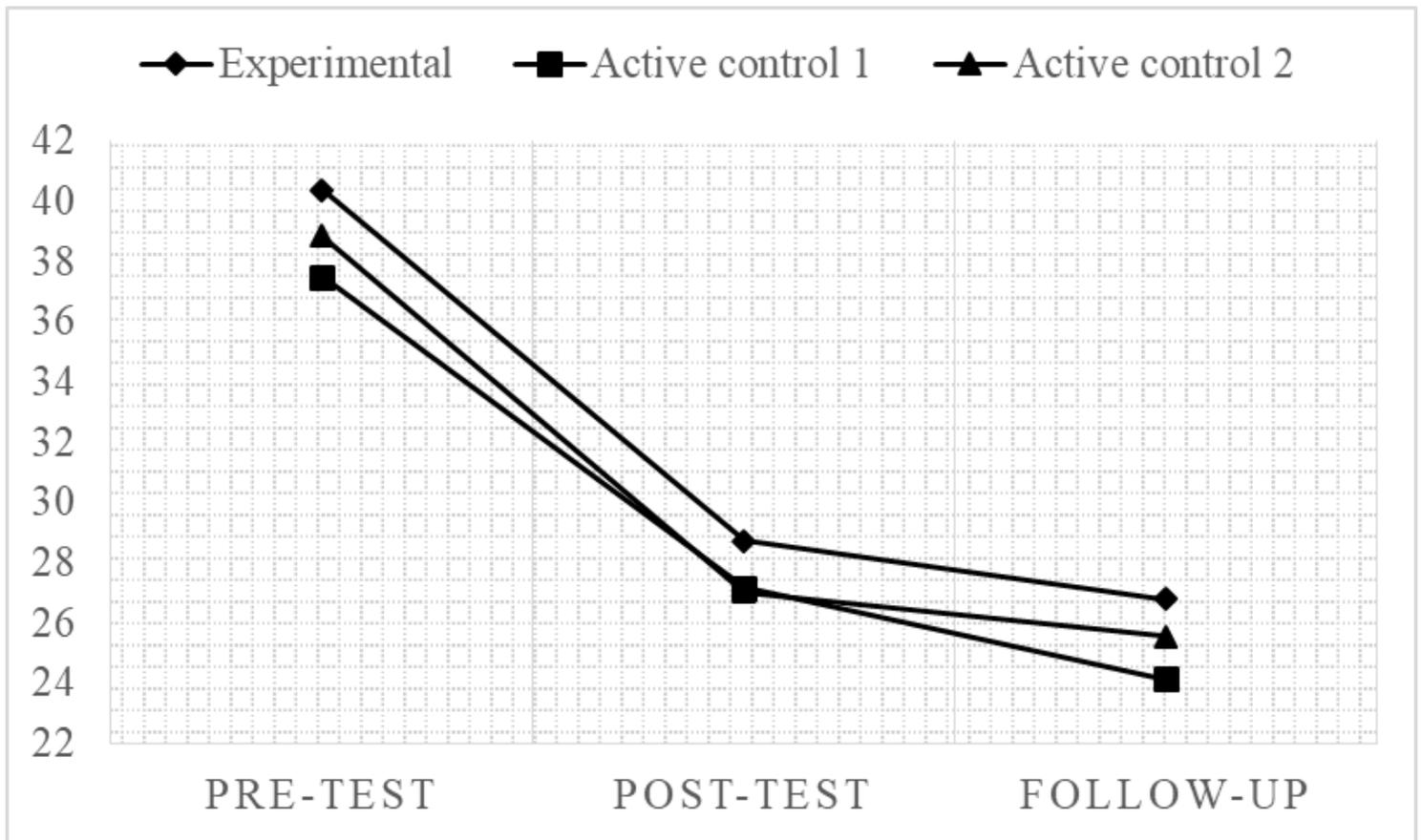


Figure 2

Craving for cigarettes (QSU-Brief) in relation to the experimental group and time of measurement

Supplementary Files

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- [Table2.jpg](#)