Published in final edited form as:
Mindfulness (N Y). 2011 September ; 2(3): 179–185. doi:10.1007/s12671-011-0057-2.

Component Processes of Executive Function—Mindfulness, Self-control, and Working Memory—and Their Relationships with Mental and Behavioral Health

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Abstract

We examined the interrelationships between higher-order cognitive functions—mindfulness, self-control, and working memory—that appear to be component processes that underlie executive function (EF) and their association with indicators of mental and behavioral health. Data were collected from first-year medical students attending a large private university in California (N=31) via a computer-based questionnaire which was administered via email hyperlink. Results indicate that self-control schedule (SCS) scores were significantly correlated with the negative dimension of positive and negative affect schedule scores ($r=-0.59$, $p<0.05$), psychological well-being scale scores ($r=0.46$, $p<0.05$), and mindful attention awareness scale (MAAS) scores ($r=0.35$, $p\leq0.10$). The planful behavior dimension of the SCS was correlated with MAAS scores ($r=0.38$, $p<0.10$), automated operation span task scores ($r=0.51$, $p<0.05$), and total SCS scores ($r=0.72$, $p<0.01$). Large and significant inverse correlations were found between current meditation practice and alcohol use ($r=-0.56$, $p<0.05$) and AUDIT scores ($r=-0.48$, $p<0.05$). Findings from this pilot study suggest that an overlap exists between some component processes of EF; however, the majority of variance in the components is not shared. Moreover, these higher-order cognitive processes appear to have protective relationships with substance use and are positively associated with self-reported meditation practice.

Keywords

Executive function; Mindfulness; Self-control; Working memory; Meditation; Substance use

Introduction

The human brain appears to have a coordinated system that directs higher-order cognitive processes, which is generally referred to as executive function (EF). EF is sometimes used

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interchangeably with the terms executive control function, executive control, or cognitive control. An interest in EF has grown with advances in cognitive psychology and neuroscience as EF appears to motivate important volitional cognitions and behaviors. EF includes attention, planning, decision making, self-regulation of emotions, initiation of goal-directed behaviors, and behavioral inhibition as well as other higher-order cognitive processes (Logan 1985; Suchy 2009). Neuroimaging studies evaluating the influence of cognitive challenges on brain activity suggest that the neuroanatomical basis of EF is located in the posterior medial frontal cortex (pMFC) and the lateral prefrontal cortex (LPFC; Ridderinkhof et al. 2004). These two brain regions appear to interact such that the pMFC acts as a monitoring system generating signals that deploy regulatory processes within the LPFC (Ridderinkhof et al. 2004).

Much of the past research on EF offers insight into the neuroanatomical functioning of higher-order cognitive processes. Little research, however, has explored interrelationships between possible self-reported component processes of EF and health-related behaviors. Consequently, it is unclear if these components represent different dimensions of the same underlying EF. Direct measurements of EF are challenging to capture because of the sheer complexity of the EF system and the advanced neuroimaging technology needed to assess EF. Consequently, neuropsychologists have developed indirect methods of measuring a variety of component processes that appear to relate to EF (Lezak 2004), which have offered increased opportunity for researchers to examine EF. In this study, we examine three higher-order cognitive functions conceptualized here as potential component processes of EF, which have gained current research interest in psychology, neuroscience and behavioral science.

Three component processes of EF considered in the previous literature include mindfulness (Cahn and Polich 2006), self-control (Beaver et al. 2007), and working memory (Engle et al. 1999). The focused attention and cognitive monitoring involved in mindful awareness appears to share some cognitive qualities with EF (Manna et al. 2010), and research has suggested mindfulness training might improve various measures of EF (Flook et al. 2010). Self-control, because it requires inhibitory mechanisms, is also suggested to be a component of EF and is modulated by the activity in the prefrontal cortex (Beaver et al. 2007). Measures of self-control and measures of EF are similarly conceptualized as important processes in regulating impulsive tendencies, in the self-regulation or modulation of emotions, sustaining attention, and anticipating behavioral consequences (Beaver et al. 2007). Working memory necessitates a higher-order ability to voluntarily focus, divide, and switch attention, and has also been conceptualized as a component process of EF (Engle 2002).

A synthesis of the examined research suggests that based on their characteristics, mindfulness, self-control, and working memory may be higher-order component functions of EF. We suggest here that the three constructs integrate both higher-order cognitive functions and attentional control (see Brown and Ryan 2003; Posner and Rothbart 2000), which appear to be coordinated by some of the same areas of the prefrontal cortex as those related to EF. Preliminary research has found relationships between these three constructs. For example, several researchers have reported that mindfulness training may increase mindfulness and also improve performance on working memory tasks (Chambers et al. 2008; Jha et al. 2010; Zeidan et al. 2010). Mindfulness training may also enhance self-control of volitional behaviors (Singh et al. 2007, 2003) and self-regulation of stress and affective reactivity (Tang et al. 2009, 2007). Perhaps, in this manner, these constructs may capture variance underlying a coordinated EF system.

The Present Study

One objective of the present exploratory pilot study was to determine the feasibility of using an electronic survey interface to collect subjective and objective measures of EF—mindfulness, self-control, and working memory—along with mental and behavioral health indices. In addition, after identifying the percentage of students who engage in meditation practices, we aimed to explore the interrelationships between component processes of EF and if these processes are correlated with affective and behavioral health as wells as meditation practice. Meditation practice was considered to be important as it has the capacity to develop affective and attentional self-regulation processes linked to EF.

Method

Participants and Procedures

Data were obtained from first-year medical students (*N*=31) attending a large private university in California who volunteered to participate in the study. Medical students are an important cohort to study as they encounter frequent and intense workload demands that place great stress on their mental health (Dyrbye et al. 2006). In addition, many medical students report substantial alcohol and substance use (Baldwin et al. 1991). Three participants failed to complete at least 50% of the survey questions, and data from those respondents were excluded from the analyses, thus the analysis sample included 28 respondents. Consent and survey procedures were approved by the University of Southern California Institutional Review Board. An email containing the hyperlink to the electronic survey was sent to the entire class of first-year medical students during the Spring 2009 semester (*N*=~150). All responses were obtained during that semester. The email provided information about the study and assured the anonymity of their responses. The online survey took approximately 20 min to complete.

Measures

Demographic data included respondent self-reported age, gender, and ethnicity (see Table 1).

Mindful Attention Awareness Scale—The mindful attention awareness scale (MAAS; Brown and Ryan 2003) is a 15-item single-dimension scale of trait mindfulness that measures the frequency of open and receptive attention to and awareness of ongoing events and experiences during day-to-day consciousness. Its response options range from 1 (almost never) to 6 (almost always). The items are reverse scored so that higher mean scores reflect a greater degree of mindfulness. The MAAS has shown good internal consistency among adult samples previously (alpha=0.84; Brown and Ryan 2003) and had comparable internal consistency in our sample (alpha=0.87).

Automated Operation Span Task—Working memory was measured with a computer-based version of the operation span task. The automated operation span task (AOSPAN; Unsworth et al. 2005) measures the capacity to learn and maintain information in an active state of memory while in the presence of interference (Engle 2002). The AOSPAN requires participants to complete two operations during the course of 15 trials. The first operation is to remember a series of three to seven letters presented sequentially on the computer monitor. Between presentations of the letters, participants solve simple math problems by indicating whether an answer to the problem shown on the monitor is true or false (e.g., 8/2+6=10). Math problems serve as distracters, thus controlled attention is required to maintain the letter sequence in short-term memory. A higher frequency of letters recalled in the correct sequence is an indication of greater working memory capacity. The AOSPAN

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has shown adequate internal consistency among adult samples in previous research (alpha=0.78; test–retest reliability r=0.83; Unsworth et al. 2005).

Self-control Schedule—A total of 21 items from the self-control schedule (SCS; Rosenbaum 1980) were used to measure self-control. The SCS defines self-control as a respondent's ability to apply self-regulation methods to the solution of common behavioral problems. Response options range from 1 (very uncharacteristic of me) to 6 (very characteristic of me). Negatively worded items are reverse-coded making higher mean scores indicate higher self-control. The SCS has shown adequate to good internal consistency among adults in previous research (alpha=0.78–0.84; Rosenbaum 1980), and comparable internal consistency was found in our sample (alpha=0.83).

Positive and Negative Affect Schedule—The positive and negative affect schedule (PANAS; Watson et al. 1988) consists of ten positive affect (PA) and ten negative affect items, which are independent dimensions of affect. PA reflects the extent to which a person feels enthusiastic, active and alert, high energy, and full of concentration. Low PA is characterized by sadness and lethargy. Higher scores in our study indicate higher PA. NA reflects subjective distress and aversive mood states such as anger, disgust, guilt, fear, and nervousness. Low NA reflects a state of calmness and serenity. Higher scores in our study indicate higher NA. The PANAS has shown good internal consistency among adults in previous research (alpha NA=0.85; PA=0.89; (Watson et al. 1988)), and comparable internal consistency was found in our sample (alpha NA=0.93; PA=0.89).

Psychological Well-being Scale—A total of 28 items from the psychological well-being scale (PWS; Ryff 1989) were used to measure the respondents' subjective evaluation of their current well-being. Response options range from 1 (strongly disagree) to 6 (strongly agree). Negatively worded items were reverse-coded making higher mean scores indicate higher well-being. The PWS has shown adequate internal consistency among adults in some previous studies (alpha=0.86–0.93; Ryff 1989), and a comparable internal consistency was found in our sample (alpha=0.93).

Past 4-Month Substance Use—Data on recent substance use were collected. A single question was asked: “About how many times have you used each of the drugs below in the last four months? (without a doctor telling you to take them, or taking more than a doctor told you to take).” A 4-month recall period can be useful to boost a student's recall as it aligns with the length of a typical school semester. Four substance use categories were queried, including alcohol, cigarettes, marijuana, and other (the “other” category included Xanax, Vicodin, Valium, OxyContin). Response choices included “never,” then resumed in increments of ten (e.g., one to ten times, 11–20 times)upto91+ times.

Alcohol use disorders identification test (AUDIT; Saunders et al. 1993): The AUDIT is a ten-item self-report of hazardous or harmful alcohol use. The AUDIT was developed by the World Health Organization and is used as a screening tool to identify those at risk for developing alcohol problems. AUDIT scores are summed across ten indicators of alcohol use behavior. Higher scores indicate higher self-reported hazardous or harmful alcohol use. We analyzed the AUDIT as a summed continuous variable because only two respondents in our sample reported meeting the recommended 8-point cutoff score for hazardous or harmful alcohol use.

Current Meditation Practice—One question was asked about current meditation practice: “Are you currently practicing one or more of these techniques?” Response options included meditation, yoga, Tai Chi, relaxation techniques, or other meditation practice.

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Respondents marked either “No” or “Yes” to indicate their involvement in current meditation practice.

Analyses

Data analyses were conducted using the SAS 9.2 software. Descriptive statistics were calculated and bivariate Spearman's rank correlation coefficients were computed. The small sample size and skewed distributions dictated the use of nonparametric statistics. With low power, only larger correlations ($r \geq 0.45$) were significant at an alpha of $p<0.05$. As an exploratory study, we present results at $p \leq 0.10$ to suggest trends, and no corrections were made for multiple analyses. As a pilot study, we interpret correlation coefficients according to established standards for the size of correlations (i.e., small, $r=0.10–0.23$; medium, $r=0.24–0.36$; large, $r \geq 0.37$; Bausell and Li 2002).

Results

Demographics

The participant ages ranged from 21 to 37 years old (*M*=24.5, SD=3.2; see Table 1). Over 21% of the sample reported current engagement in some form of meditation practice. More females (44%) than males (7%) reported engaging in current meditation practice. Over 70% of the respondents reported using alcohol, and over 25% reported smoking cigarettes within the past 4 months (see Table 2). AUDIT scores indicated that two respondents (7% of the total sample) met the AUDIT criteria for hazardous or harmful drinking (AUDIT, *M*=4.8, SD=2.9).

Component Processes of EF

The MAAS correlated with the SCS at $p<0.10$ (see Table 3), but less with the AOSPAN. We found little association between SCS and AOSPAN scores. Although not shown in Table 3, upon closer examination, the Planful Behavior subscale scores of the SCS measure did show a large size correlation with the total SCS scale scores ($r=0.72$, $p<0.01$), the MAAS scores ($r=0.38$, $p<0.10$), and AOSPAN scores ($r=0.51$, $p<0.05$).

Component Processes of EF and Mental Health Measures

Neither MAAS scores nor AOSPAN scores were correlated with the positive and negative affect schedule-negative affect (PANAS-N), positive and negative affect schedule-positive affect (PANAS-P), or PWS scores. However, SCS scores were correlated with all three of these mental health measures. SCS scores had a large inverse and significant correlation with the PANAS-N ($r=-0.59$, $p<0.05$) and a large positive and significant correlation with the PWS ($r=0.46$, $p<0.05$).

Component Processes of EF and Substance Use

None of the intercorrelations between the three component processes of EF was statistically significant based on our sample size. However, MAAS scores had expected inverse correlations with each of the four substance use categories and with the AUDIT measure of hazardous or harmful alcohol use. AOSPAN scores had a nonsignificant medium-size inverse correlation with both alcohol use and the AUDIT. The SCS correlation coefficients functioned in a similar manner as did the AOSPAN correlation coefficients with the substance use categories.

Component Processes of EF and Meditation Practice

None of the three component processes of EF was significantly correlated with the current meditation practice based on our sample size. However, the small-to-medium size correlations identified were in the expected direction and are of a magnitude found to be significant with larger samples. However, large and significant inverse correlations were found between current meditation practice and alcohol use ($r=-0.56$, $p<0.05$) and AUDIT scores ($r=-0.48$, $p<0.05$).

Discussion

This pilot study explored the interrelationships between three constructs that we conceptualized as component processes of EF (i.e., mindfulness, self-control, and working memory), and the relationship between these processes and mental and behavioral health measures and meditation practice. Based on our analyses, the majority of variance in the three component processes of EF appears to be distinct. However, the preliminary results suggest that mindfulness and self-control have a shared variance that may suggest some underlying shared EF system. This finding is consistent with a previous research reporting a positive relationship between mindfulness and increased self-control of behavior (Singh et al. 2003). The self-report data collected in the present study are also consistent with neuroimaging data, which have also found preliminary relationships between mindfulness and self-regulation (Tang et al. 2009).

Upon closer examination, our data suggest that the planful behavior subscale of the SCS is correlated strongly with both working memory and mindfulness. Although this finding is only preliminary, it is consistent with previous work that supports a positive relationship between working memory scores and self-control (Schmeichel et al. 2008). This is an important exploratory finding considering that goal-oriented planning is a main feature of EF. Thus, planful behavior, as a self-report measure, is one possible intersection where all three measureable component processes of EF appear to be significantly related. Further research is warranted with large samples to examine the planful behavior subscale and how it relates to higher-order cognitive measures of EF and health behavior.

Self-control stood out relative to mindfulness and working memory in its association with mental health measures examined in our study. Our findings indicate that self-control has a large positive correlation with measures of mental health. It is important to note that our self-control measure consists of the dimensions of affective thought management and coping efficacy. Therefore, our findings are not surprising considering that the self-control measure captures the respondents' ability to regulate affect and feel confident in applying coping responses. These findings are consistent with previous research indicating a positive relationship between self-control and improved affect and related emotional responses (Tangney et al. 2004; Tice et al. 2007).

Our findings do not support either mindfulness or working memory to be associated with positive affect, negative affect, or psychological well-being. These findings are not consistent with previous research. Previous studies, based on larger sample sizes, report significant medium-size correlations between MAAS scores and PANAS-P (i.e., positive affect) scores and satisfaction with life scores (Brown and Ryan 2003). The research by Brown and Ryan (2003) also indicates large-size inverse correlations between mindfulness MAAS scores and PANAS-N (i.e., negative affect) scores. We are unsure why our correlations coefficients were not stronger among our sample of medical students beyond the small sample size and difference in method of data collection (i.e., computer-based questionnaire). Further studies are needed before these relationships can be interpreted among this cohort.

Our findings indicate that current meditation practice has strong inverse correlations with both alcohol use and hazardous or harmful alcohol use. A vast majority of medical students in our sample reported alcohol use, and although this evidence in no way indicates causality, it does support the growing area of research which suggests that meditation and related practices might be useful in addressing substance use behavior (Breslin et al. 2002). Considering the high percentage and frequency of alcohol use among medical students, a promising area of future research is to examine the temporal relationships between meditation practices and substance use to determine if meditation and related practices exert a temporal protective effect against substance use. Recent studies do suggest the potential of meditation-related practices such as mindfulness to be effective modalities for preventing and treating substance use and abuse (Alfonso et al. 2011; Breslin et al. 2002; Witkiewitz and Bowen 2010).

The findings from our study are limited. The small sample of self-selected volunteers used to yield our cross-sectional data limits the external validity of our findings and does not allow for interpretations of causality. Future studies with adequate sample sizes are needed to re-examine relationships between the component processes of EF examined in our study to corroborate or refute our findings. In addition, future studies should consider the use of factor analysis procedures to test more directly if EF serves as a higher-order factor comprised, at least partially, of mindfulness, self-control, and working memory dimensions. Additional higher-order cognitive measures such as attentional control and self-regulation measures could also be considered in this line of research. Finally, prospective studies are needed to guide our understanding of the temporal relationships between component processes of EF and measures of mental and behavioral health as well as meditation practice.

Conclusions

The initial findings from this exploratory study have possible implications for disease prevention and health promotion research among medical students. Medical students are expected to deal with various stressors under high cognitive demand, making them vulnerable to maladaptive coping responses such as substance use. Current meditation practice was reported by almost a quarter of medical students in our sample, indicating an interest in this type of intervention modality. Considering that current meditation engagement was protective of substance use, specifically against alcohol use and harmful/hazardous use, perhaps meditation interventions are a promising avenue to increase medical student health considering they are a population with relatively high rates of alcohol use. Meditation modalities, such as mindfulness meditation, have recently been integrated into some medical school programs with promising results (Drolet and Rodgers 2010; Hassed et al. 2009). Further research examining meditation interventions among medical students is needed, and this research should consider components processes of EF as possible mechanisms linking meditation to mental and behavioral health.

Acknowledgments

This work was partially supported by the National Cancer Institute [T32 CA09492 to D.S.B.] and by the Agency for Healthcare Research and Quality [T32 HS00046-14 to J. G.]. We thank the study participants for dedicating their valuable time to complete our assessments.

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Table 1

Characteristics of first-year medical student sample (N=28)

Variable	Number	Mean	SD	Range	Percent
Age		24.5	3.2	21–37	
Gender					
Male	14				50
Female	14				50
Ethnicity					
White	20				71
Hispanic	4				14
Middle Eastern	2				7
Other	2				7
Current meditation practice					
Yes	6				21
No	22				79
Component processes of EF					
MAAS		3.2	0.7	1.6–4.5	
SCS		3.9	0.6	2.4–5.2	
AOSPAN		60.8	9.2	37.0–75.0	
Mental health					
PANAS-P (positive affect)		3.4	0.8	1.6–4.8	
PANAS-N (negative affect)		2.2	0.9	1.1–4.4	
PWS		3.8	0.7	2.1–4.8	

Not all percent values sum to 100% due to rounding

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Table 2

Self-reported frequency of substance use by drug category

Variable	N (28)	Percent
Past 4-month substance use		
Alcohol		
Never	8	29
1–10 times	11	39
11–20 times	2	7
21+ times	7	25
Cigarettes		
Never	21	75
1–10 times	5	18
11–20 times	1	4
21+ times	1	4
Marijuana		
Never	26	93
1–10 times	1	4
11–20 times	1	4
21+ times	0	0
Other substances		
Never	26	93
1–10 times	2	7
11–20 times	0	0
21+ times	0	0

Table 3

Correlation matrix for component processes of EF, health measures, and meditation (*N*=28)

Variable	MAAS	AOSPAN	SCS	PANAS-P	PANAS-N	PWS	Alcohol	Cigarettes	Marijuana	Other	AUDIT
AOSPAN	0.04										
SCS	0.35*	0.07									
PANAS-P	0.01	0.01	0.25								
PANAS-N	0.01	−0.10	−0.59**	0.28							
PWS	0.01	0.04	0.46**	0.65**	−0.27						
Alcohol	−0.29	−0.28	−0.19	0.08	0.29	0.06					
Cigarettes	−0.16	0.24	0.21	0.62**	0.04	0.50**	0.48**				
Marijuana	−0.13	0.01	0.01	0.46**	0.20	0.26	0.48**	0.52**			
Other	−0.16	0.08	−0.10	0.30	0.07	0.34	0.41	0.61**	0.47**		
AUDIT	−0.13	−0.25	−0.26	0.20	0.60**	−0.24	0.63**	0.25	0.32	−0.02	
Meditate	0.14	0.30	0.21	0.09	−0.34	0.28	−0.56**	0.05	−0.17	−0.17	−0.48**

Spearman's rank order correlation coefficients

* $p \leq 0.10$

** $p < 0.05$