THE JOURNAL OF CHILD PSYCHOLOGY AND PSYCHIATRY

ACAMH THE ASSOCIATION FOR CHILD AND ADOLESCENT MENTAL HEALTH

Journal of Child Psychology and Psychiatry 58:4 (2017), pp 361–383 doi:10.1111/jcpp.12675

Annual Research Review: On the relations among self-regulation, self-control, executive functioning, effortful control, cognitive control, impulsivity, risk-taking, and inhibition for developmental psychopathology

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Background: Self-regulation (SR) is central to developmental psychopathology, but progress has been impeded by varying terminology and meanings across fields and literatures. **Methods:** The present review attempts to move that discussion forward by noting key sources of prior confusion such as measurement-concept confounding, and then arguing the following major points. **Results:** First, the field needs a domain-general construct of SR that encompasses SR of action, emotion, and cognition and involves both top-down and bottom-up regulatory processes. This does not assume a shared core process across emotion, action, and cognition, but is intended to provide clarity on the extent of various claims about kinds of SR. Second, top-down aspects of SR need to be integrated. These include (a) basic processes that develop early and address immediate conflict signals, such as cognitive control and effortful control (EC), and (b) complex cognition and strategies for addressing future conflict, represented by the regulatory application of complex aspects of executive functioning. Executive function (EF) and cognitive control are not identical to SR because they can be used for other activities, but account for top-down aspects of SR at the cognitive level. Third, impulsivity, risk-taking, and disinhibition are distinct although overlapping; a taxonomy of the kinds of breakdowns of SR associated with psychopathology requires their differentiation. Fourth, different aspects of the SR universe can be organized hierarchically in relation to granularity, development, and time. Low-level components assemble into high-level components. This hierarchical perspective is consistent across literatures. **Conclusions:** It is hoped that the framework outlined here will facilitate integration and cross-talk among investigators working from different perspectives, and facilitate individual differences research on how SR relates to developmental psychopathology. **Keywords:** Attention; self-control; executive function; impulsivity.

Introduction

Regulation is the ongoing, dynamic, and adaptive modulation of internal state (emotion, cognition) or behavior, mediated by central and peripheral physiology.[1] It draws upon numerous aspects of the mind, including such capacities as executive functioning (EF). It includes regulation of and by others (called *extrinsic*) particularly in early life (Cox, Mills-Koonce, Propper, & Gariepy, 2010) and also throughout development and into adulthood (Gross, 2015). Regulation of and by oneself (*intrinsic*) emerges increasingly with development and is called *self-regulation* (Eisenberg & Zhou, 2016). Figure 1 shows that self-regulation (SR) is a portion of 'regulation' and includes top-down (deliberate) and bottom-up (automatic) aspects discussed later. This review is about SR.

Self-regulation holds almost unparalleled importance to mental health. Poor SR in some form is related to attention deficit/hyperactive disorder (ADHD) and internalizing and externalizing psychopathology (Calkins, Graziano, & Keane, 2007; Eisenberg et al., 2009; Espy, Sheffield, Wiebe, Clark, & Moehr, 2011; Martel & Nigg, 2006; Olson, Sameroff, Kerr, Lopez, & Wellman, 2005; Petitclerc et al., 2015; Rothbart & Bates, 2006; Wakschlag et al., 2012), addiction (Zucker, Heitzeg, & Nigg, 2011), depression (Wang, Chassin, Eisenberg, & Spinrad, 2015), bipolar disorder risk (Tseng et al., 2015), schizophrenia, autism spectrum disorder, obsessive–compulsive and habit disorders (Fineberg et al., 2014), eating disorders, some personality disorders (Nigg, Silk, Stavro, & Miller, 2005), and others. Processes of SR are integral to the emergence of psychopathology (Rothbart, 2011). Exemplifying a developmental cascade of risk, problems in SR predict future obesity, unintentional injury, homicide, and suicide in youth (van den Ban et al., 2014; Barkley & Cox, 2007; Prager, 2009). Children's SR informs social and intellectual developmental milestones (Blair & Razza, 2007; Kochanska, 1997; Padilla-Walker & Christensen, 2011; Spinrad et al., 2006), and is a leading predictor of academic outcome, occupational success, and health (Clausen, 1995; Tangney, Baumeister, & Boone, 2004).

While it is clearly important, different aspects of SR may relate to different outcomes in distinct ways

Conflict of interest statement: No conflicts declared.

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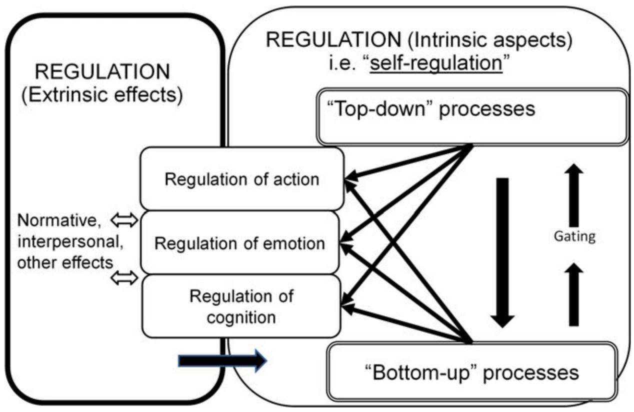

Figure 1 Self-regulation (SR) entails regulation by oneself (called intrinsic) as opposed to regulating or being regulated by others. SR has top-down and bottom-up components that mutually influence one another. Bottom-up processes are both targets of and sources of regulation. Bottom-up processes can interfere with top-down SR, but they also help regulate one another and regulate top-down control via a threshold referred to as 'gating' which implies continual information updating. Extrinsic regulatory effects can work via both bottom-up and top-down intrinsic processes; the arrow at the bottom illustrates their cross-talk via reactive (bottom-up) processes, which are most heavily studied in child development (e.g. behavioral inhibition as described in the text or parental soothing of a child). The present review is concerned only with intrinsic processes or SR, not regulation generally. Not to scale [Colour figure can be viewed at wileyonlinelibrary.com]

(Morris, Keane, Calkins, Shanahan, & O'Brien, 2014; Wakschlag et al., 2014). Unfortunately, integration of findings is impeded by differences in terminology, levels of analysis, and measurement among related constructs across fields. SR (or equivalent) is studied heavily in personality, social, and cognitive psychology, developmental science, clinical psychology, psychiatry, economics, sociology, neuroscience, and medicine.

Investigators in these fields have approached SR in multiple ways without a consensus framework for decades (Karoly, 1993). Some of this variation represents useful subdivision of the construct domain for analysis from different perspectives. Furthermore, because SR reflects an adaptive, dynamic, complex process and system or systems, verbal formulas or linear equations will at best capture only part of it. Thus, some variation in approach is understandable.

Nonetheless, the range of constructs can be confusing. It includes (with key reviews for background): executive functioning (Diamond, 2013), emotion-, mood-, and affect-regulation (Gross, 2015), temperament (Rothbart, 2011; Rothbart & Derryberry, 1981), effortful control (EC) (Eisenberg et al., 2013; Rothbart, 2011), ego under-control (Block & Block, 1980), reactive control (Derryberry & Rothbart, 1997), behavioral inhibition (Kagan & Snidman, 2004), impulse control and impulsivity (Madden & Bickel, 2010), risk-taking (Luciana, 2013), cognitive control (Botvinick & Cohen, 2014), working memory (Baddeley, 2012; D'Esposito & Postle, 2015; Kane & Engle, 2002), inhibition (Logan & Cowan, 1984; Nigg, 2000; Simpson et al., 2012), delay of gratification (Sethi, Mischel, Aber, Shoda, & Rodriguez, 2000), will/willpower (Ainslie, 2005), venturesomeness, constraint or conscientiousness (Sharma, Markon, & Clark, 2014), planfulness (Clausen, 1995), and more. Many of these are related but there is no agreement on how so. Table 1 provides a glossary of key terms.

Calls for clarification have multiplied and been helpful (Blair & Ursache, 2011; Diamond, 2013; Eisenberg, Smith, & Spinrad, 2011; Rothbart, 2011; Sharma et al., 2014; Welsh & Peterson, 2014; Zhou, Chen, & Main, 2012). Yet the effort remains incomplete. Morrison and Grammer (2016) colorfully warn of 'conceptual clutter' and 'measurement mayhem'. This review offers a roadmap for a unified approach in developmental psychopathology and clinical science. A set of constructs is proposed within which further subdomains can be added for particular purposes, to foster integration, delineation of mechanisms, and prediction.

General issues

Definition of terms and scope of review

Rather than a systematic review or meta-analysis, I briefly orient readers to historical linkages and then emphasize recent literature. I draw primarily on cognitive science and neuroscience, developmental science, and social-personality psychology in addition to the clinical psychopathology literature, and prioritize constructs related to psychopathology. Table 1 defines the most common terms as intended herein. Before moving to important concept distinctions, I note selected background issues that have caused confusion.

First, SR is not static. It develops through critical periods from early life to adulthood, in nonlinear and stage-sequenced fashion, via a hierarchical, cascade process. Low-level capacities assemble into more complex capabilities, congruently with development of physical and neural systems and the gradual internalization of control during childhood (Cox et al., 2010; Masten & Cicchetti, 2010; Smith & Thelen, 2003; Thelen, Schoner, Scheier, & Smith, 2001). Adolescence, for example, is typified by asynchronous, nonlinear development across different kinds or aspects of SR (Casey, 2015), moderated by emotion context (Cohen et al., 2016). This principle of hierarchical differentiation helps with integrating constructs later.

Second, needless confusion arises from confounding measurement and construct – they are far from isomorphic. The same measures can tap related constructs; and laboratory-based observations, computerized reaction time and accuracy tasks, and rating scales have weak intercorrelations (McAuley,

Table 1 Definitions and glossary of major terms as relevant to in the current essay

Action selection: Cognitive or mental process of determining which of two possible actions to take (turn left or turn right)
Attentional inhibition: See inhibition, attentional
Behavioral inhibition: The bottom-up interruption of a behavior sequence in response to novel, ambiguous, or threatening stimulus; mediated by internal state of anxiety. A component of bottom-up and reactive aspects of self-regulation (SR). Also referred to as *reactive inhibition.* See Nigg (2000) for more explanation and Kagan and Snidman (2004) for in depth elaboration. This term is sometimes incorrectly used interchangeably with 'response inhibition', but *behavioral* inhibition is a bottom-up process and *response* inhibition is a top-down process (Nigg, 2000)
Behavioral under-control: A high-level trait connoting spontaneous response to internal and external stimuli. See Block and Block (1980) and Zucker et al. (2011) for further conceptualization. Could be related to the metatrait of 'Stability' in the Big Five framework
Cognitive control: It has been defined as 'the ability to flexibly adjust behavior in the context of dynamically changing goals and task demands' (Carter & Krus, 2012, p. 89); as 'a set of superordinate functions that encode and maintain representation of the current task...[and engage] working memory...attention...action selection and inhibition' (Botvinick & Braver, 2015, p. 85); while related to executive functioning, greater emphasis on working memory, for example it is 'active maintenance of goals and means to achieve them' (Miller & Cohen, 2001). Herein, closely related to 'lower level' executive function (EF) and enables 'higher level' EF
Control, behavioral: See behavioral under-control
Control, cognitive: See Cognitive control
Control, executive. See Executive control
Control, interference: See Interference control
Control, proactive: See Proactive control
Control, reactive: See Reactive control
Conflict: A general term that refers to the following kinds of conflict: (a) prediction failure (conflict between expected and actual event or outcome of an action), (b) perceptual (interference between goal-relevant and goal-irrelevant but similar-seeming information), (c) response (two responses are triggered by stimulus, but only one is goal-relevant), (d) goal conflict (available action advances one goal at the expense of another goal), (e) activation of irrelevant cognition, emotion, or action to a goal. At the neural level, neural networks are always working in parallel and frequently if not constantly in competition as part of their mutual SR
Conflict monitoring: Detection of any conflict that is between expected and actual outcome, between perceptual targets and distractors, or between two conflicting response triggers. Often associated with activation in anterior cingulate cortex
Effortful control: A dispositional trait-level representation that represents the tendency to be able to employ top-down control to self-regulate. It is seen as emerging from one aspect of EF or cognitive control, executive attention, but also, with development, including other capabilities (Rothbart, 2011). I argue here that effortful control (EC) maps at the cognitive level onto cognitive control, that is, basic controlled operations that underpin complex cognition. When cognitive control is used in the service of SR, that essentially is EC
Ego control. See behavioral under-control
Ego resiliency: The capacity to modulate self-control (or ego control) in either direction to adapt to a situation. Flexible adaptation and use of different problem-solving strategies is a hallmark of ego resiliency (Block & Block, 1980). Broadly overlaps the domain space taken by SR but quite distinct in terms of theoretical basis and specification and adds the critical component of flexibility in application of control
Emotion regulation: Adjustment of emotional state or expression to meet goals or to maintain homeostatic or allostatic state; includes both top-down (strategic) efforts (e.g. redirect attention) and bottom-up (e.g. arousal state) processes (Gross, 2014); it includes both intrinsic and extrinsic regulation and therefore is partially outside the domain of SR described here
Executive Attention: Overcoming attention to a competing stimulus, to focus attention on a goal-relevant stimulus. A top-down form of attention, similar to endogenous attention and focused attention in other literatures
Executive control: Synonym for top-down cognition, closely related to cognitive control and to EF
Executive function: Partially independent, top-down cognitive functions involved in top-down control of behavior, emotion, and cognition; support goal-directed behavior and cognition; and can be employed for top-down SR (Barkley, 2012). Other definitions emphasize rule-governed cognition; all definitions agree that EF reflects cognitive operations responding to an internal (top-down) goal. Dispute continues on whether there is a unitary 'core' to all EF. Includes 'lower level' operations like working memory and inhibition that overlap with cognitive control, as well as elaborated combinations of these operations that create complex cognition (Diamond, 2013) and include planning and coping strategies
Impulsivity: Nonreflective stimulus-driven action when a later-rewarding goal-relevant response was also available. May be adaptive or maladaptive depending on context and degree of inflexibility as context changes. Mediated by both bottom-up processes (e.g. spontaneous reward valuation/discounting) and top-down process (e.g. biasing from prior goals; response inhibition)
Inhibition, Attentional: Ignoring a stimulus that is competing for attention to enable focus on goal-relevant information – in that sense, closely related to interference control and to executive attention. However, this top-down function is controversial; computational models suggest that inhibition may not be necessary to focus attention as simple inactivation of competing signals may be enough. Note that although not used in this way typically, attention can be inhibited by bottom- up signals as well (e.g. anxiety driving attention away from an immediate stimulus and toward another one)
Inhibition, Reactive: From Nigg (2000), reactive inhibition was use to designate the bottom-up interruption of a behavior, thus, here it is the same as bottom-up behavioral inhibition, and also closely related to *reactive control* (below)
Inhibition, Response: Top-down ability to intentionally or effortfully suppress a triggered behavior to sustain behavior toward a goal; a component of EC and of EF. See Logan and Cowan (1984), Nigg (2000) and Simpson et al. (2012)
Interference control. Ignoring (inhibiting, suppressing, or de-activating) internal or external competing information to protect working memory or to focus attention on goal-relevant information; it is related to selective attention and attentional inhibition (Diamond, 2013)
Proactive control: In the cognitive literature, refers to expectancy-based activation of cognitive control (maintaining goal activation to bias responding) prior to an anticipated conflict or challenge (Braver, 2012). It is in contrast to reactive control, which is the activation of cognitive control after a change or conflict is detected

(continued)

Table 1 (continued)

Reactivity: From Rothbart's model, means sensitivity to negative affects (fear, frustration, distress, sadness) and positive affects (smiling, laughter, approach). Related to bottom-up appetitive processes as described in the text
Reactive control: Has two meanings in two literatures. In the cognitive literature, is differentiated from proactive control, where it refers to the activation of cognitive control after an error or a sudden change in conditions (i.e. response/goal conflict or other conflict) is detected, while proactive control means activation of control in expectation of challenge or conflict (Braver, 2012). In the developmental literature, it refers to bottom-up control, closely related to behavioral inhibition (see behavioral inhibition; Derryberry & Rothbart, 1997)
Reactive aspects of SR: Refers to bottom-up or relatively automatic responses that suppress behavior or alter regulatory state, such as anxious interruption of behavior in response to novelty, change in arousal level in response to potential reward, or spontaneous estimation of reward value; and spontaneous attentional capture by salient stimuli
Reactive inhibition: See inhibition, reactive
Response inhibition: See inhibition, response
Risk-taking: Adaptive or maladaptive selection of rewarding behavioral option in the face of high probability of loss, attributed to steep discounting of loss probability (Reward sensitivity + punishment insensitivity). Also defined as the option with the most variable outcome; this is only true if a high possible loss is paired with a high possible gain. May be bottom-up (e.g. 'impulsive') or top-down (i.e. 'deliberative' or strategic); adaptation value depends on behavioral payoff
Self-control: Has been used both in a very specific sense in the developmental literature to connote the capacity to resist temptation or inhibit a dominant response or activate a subdominant response (Diamond, 2013; Rothbart, 2011). In that sense it means override of a stronger, stimulus-driven representation with a weaker, memory-driven representation. It has also been used in the social and other literatures in a broad sense to refer to voluntary cognition and behavior or effectively, top-down aspects of SR (Duckworth & Kern, 2011; Fujita, 2011); here it encompasses also control strategies such as reappraisal, precommitment, and others
Self-regulation: The *intrinsic* processes aimed at adjusting mental and physiological state adaptively to context. Encompasses cognitive control, emotion regulation, and top-down and bottom-up processes that alter emotion, behavior, or cognition to attempt to enhance adaptation (or to achieve an explicit or implicit goal or goal state). Also involves physiological systems (Calkins & Fox, 2002) as well as homeostatic and allostatic mechanisms in response to stress, challenge, or new information; encompasses strategic/deliberative as well as reactive/automatized processes and their reciprocal influences. However, the present review excludes allostatic and homeostatic processes and some theorists deny these are part of SR
Sensation seeking: For present purposes, risk-taking, due to their high correlation and similar factor loadings. However, sensation seeking can also be framed as a high-order personality factor
Signal detection. Perceptual distinction of target signal from noise (is that my friend I hear speaking in the crowd?), differentiating two different stimuli (is it a bear or moose?), or signal detection (did I just hear the phone?). Amenable to mathematical modeling and therefore useful in process and mechanism models of components of SR
Switching. Attention switching means looking at the same problem from two different perspectives; task-switching means changing tasks in response to a metagoal. Both are examples of top-down cognition or of executive functioning
Venturesomeness: For present purposes, risk-taking at the personality trait level
Will/willpower. The term *willpower* is rarely used but when it is, the usage varies between (a) interchangeable with effortful control as defined here and (b) interchangeable with the high-level self-control capacities of persistence and long-term strategies, what Duckworth and colleagues call 'grit'. Thus, while it generally refers to a deliberate resistance to an immediately activated stimulus-driven response (Ainslie, 2005; Diamond, 2013; Kross & Mischel, 2010; Zhou et al., 2012), in some usages 'will' also refers to grit or conscientiousness
Working memory: Has multiple definitions. Fundamentally, the ability to hold multiple things in mind at once, while mentally manipulating one or more of them (Baddeley, 2012). While different models are related, the model adopted in the text is closely related to that offered by Engle (Kane & Engle, 2002) as the combination of short-term memory and controlled or 'executive' attention or interference control; that is, working memory in that model requires inhibition of competing information to protect working memory. I do not assume that working memory requires attentional inhibition but do assume it requires executive attention

Chen, Goos, Schachar, & Crosbie, 2010), although coherent patterns can be identified (Duckworth & Kern, 2011). My focus is on *concepts,* not measures.

Third, models of SR typically start with a *dual-process* logic making it important to clarify what is regulated, versus what is regulating, in a given context. Dual-process conceptions emanated from the classic distinction between automatic and deliberate attention (Posner & Snyder, 1975; Schneider & Shiffrin, 1977), then generalized to most domains of psychology (Evans, 2008; Evans & Stanovich, 2013). While ultimately a dual-process account is insufficient, it is valuable. The dual-processes are described in different ways, such as automatic/deliberate; bottom-up/top-down; exogenous/endogenous; implicit/explicit; gist/verbatim; unconscious/conscious; and to remain agnostic, Type I/Type II. Models of SR propose at least one top-down 'control' aspect and one or more bottom-up processes, the latter as *targets* of regulation (Gross, 2014; Rothbart, 1981; Shulman et al., 2016) and also as *regulating*. I explain further below.

Fourth, while a mechanistic model is not my goal, the process literature needs to be recognized as crucial, as it will aid in future concept clarification. I borrow from it selectively. It includes psychological models (Baumeister & Heatherton, 1996; Carver & Scheier, 2001; Gross, 2015; Mischel & Shoda, 1995), a range of mathematical decision models including signal detection (Green & Swets, 1966; Sergeant, Oosterlaan, & van der Meere, 1999; Wickens, 2002), timing (Gibbon, Church, Fairhurst, & Kacelnik, 1988; Wearden & Lejeune, 2008), discounting (Mitchell, Wilson, & Karalunas, 2015; Killeen, 2009), foraging (Stevens & Stephens, 2010), and accumulative models (Huang-Pollock, Karalunas, Tam, & Moore, 2012; Smith & Ratcliff, 2004), their computational extensions (Botvinick & Cohen, 2014), and neural accounts (Petersen & Posner, 2012). Feedback principles have been fundamental to understanding brain function for nearly a century (von Uexküll, 1926); and to process models of SR for half a century up to the present (Gross, 2015; Miller, 1956; Verbruggen, McLaren, & Chambers, 2014). Computational models also operationalize the recursive optimization logic consistent with cybernetics – including in particular input from bottom-up processes (Botvinick & Cohen, 2014).[2] Most theorists therefore agree that bottom-up processes must participate in SR (thus, Figure 1).

I therefore next clarify the crucial bottom-up and top-down concepts. Then, I address three clarifications: (a) domain-general SR; (b) similarity of executive functioning, EC, and cognitive control; and (c) distinctions among impulsivity, inhibition, and risk-taking. I conclude with a proposed descriptive organization of the SR domain.

Target/source of SR in relation to top-down/bottom-up process

While this distinction will prove quite useful, it has to be noted that bottom-up (reactive, or Type I) and top-down (deliberate, or Type II) are on a continuum, not absolute categories (Evans & Stanovich, 2013; MacLeod, 1991; Nigg, 2000; Posner & Snyder, 1975; Schneider & Shiffrin, 1977) in part due to successive reciprocal neural feedback loops (Fuster, 1997). For instance, top-down systems can activate, suppress, or bias bottom-up responses (Avital-Cohen & Tsal, 2016; Corbetta, Patel, & Shulman, 2008; Ochsner et al., 2009). In turn, bottom-up systems can activate goal-related behavior via priming or other effects, limiting the effects of top-down process (Verbruggen, McAndrew, Weidemann, Stevens, & McLaren, 2016).

Type I ('bottom-up' or automatic) processes in relation to SR. Type I processes are automatic, stimulus-driven, rapid, and do not require mental capacity. They are called 'bottom-up' as an evocative shorthand because they are elicited by sensory (external) stimuli and because human brain-imaging and primate single cell recording studies link them with 'feed-forward' neural signaling (e.g. subcortical to cortical, or posterior to anterior cortical signaling; Depue & Lenzenweger, 2006; Miller & Buschman, 2012). Bottom-up processes are not unitary (Evans & Stanovich, 2013), as shown in Table 2. These are classically the *targets* of SR; for example, a child must regulate her excitement. However, they also can be *regulatory* in at least four ways. Because this is not always recognized, I elaborate briefly.

First, they modulate and optimize one another. For example, incentive approach and avoidance are modulated by associative and instrumental learning history (a baby's excitement when a mother pulls out a toy they played with before). Second, bottom-up processes can prime, activate, or modulate top-down processing (Bargh & Ferguson, 2000). Nigg (2000, 2001), following earlier authors (Derryberry & Rothbart, 1997; Eisenberg et al., 1997; Rosenberg &

Table 2 Key bottom-up mental processes that can be targets of regulation or can be regulatory[a]

Process	Example
Innate and unconditioned response	Child reaches directly for an object rather than around an obstacle; attention is captured by a looming object
Reflexes	Startle to a loud noise
Single stimulus learning (habituation, sensitization)	Learning to ignore an uninformative signal; for example a child ignores repeatedly unenforced warnings of punishment
Habit formation/associative learning (classical conditioning)	A child learns to wake up when his bladder is full
Operant (instrumental) learning	A dog learns to sit to earn a treat; a child learns to say please to earn parental praise
Appetitive approach (positive affect; excitement, hope; but also possibly anger)[b]	Drawing upon both conditioned and learned signals; for example a child comes to the kitchen upon smelling cookies; a smoker stops the car upon seeing a party store
Avoidance (negative affect; anxiety, fear)[c]	Converse to approach; a child avoids a stranger; driver spontaneously takes foot off gas on seeing police

[a]The neural bases of these bottom-up operations are extensively described in the literature but not described here due to space limitations. Note that debate remains about how many systems exist; for example, while habit formation is a well-described phenomenon important to psychopathology, controversy remains about whether associative or implicit learning is a separate system (Shanks, 2010).

[b]The biological validity of approach and avoidance affect is supported by scalp electrical recordings: Approach ('positive' but including aspects of anger) emotions are associated with left-lateralized frontal EEG activation, and avoidance emotions (fear, anxiety, possibly sadness and other aspects of anger) with right-lateralized frontal EEG activation (Compton & Heller, 1998; Davidson, 1992); as well as by experimental mathematical representations as described later in the text.

[c]Approach and avoidance, of course, also operate at other levels of analysis, such as reflex (pulling hand away from the stove), and higher order goal setting. Here, the terms pertain specifically to the appetitive systems. The term fear can be controversial; I bypass that controversy here but note that further debate on the best term for reactive motivations is likely. Further, fear and anxiety have partially distinct neural correlates, but that is likewise beyond my scope here.

Kagan, 1989; Rothbart, 1981), highlighted that bottom-up, reactive processes related to (a) approach and (b) fear/avoidance are a particularly important part of SR of action and cognition. For example, Table 2's avoidance, also called *behavioral inhibition* (Table 1) is activated in response to novelty, uncertainty, or other cues for possible harm. It inhibits action and redirects attention (Depue & Lenzenweger, 2006; Gray, 1982; Kagan & Snidman, 2004). A child spontaneously lowers his voice and redirects attention when an unknown older child enters the room. Third, top-down operations can be automatized for particular contexts (e.g. due to learning; Bargh & Ferguson, 2000); now automatic, they remain regulatory (Dijksterhuis & Strick, 2016; Marien, Custers, Hassin, & Aarts, 2012; Papies & Aarts, 2011; Verbruggen et al., 2014). In fact, we automatize as much as possible (Bargh & Ferguson, 2000), due to costs of control; control depends on motivation, capacity, or both (Botvinick & Braver, 2015). Fourth, they support top-down regulation by providing goal-relevant information (threat or reward cue information; prior learned associations) to working memory, when cued. Figure 1 therefore includes bottom-up processes as part of SR. We return to them when considering impulsivity and risk-taking later.

Type II ('top-down' or deliberate) processes in relation to SR. Most SR literature focuses on Type II (top-down or deliberate) processes. Top-down processes are subjectively deliberate, slow, sequential, require working memory, and are capacity-limited [the separate question of resource-limitation is complex (Hagger & Chatzisarantis, 2016); for discussion see the online Appendix S1]. They engage to address novel problems, to resolve conflict or resolve coactivation (Table 1), or to prepare for an anticipated goal or challenge. They are called 'top-down' because they respond to internal mental representations (such as a goal or a rule) rather than external (sensory) stimuli, and because human imaging and primate single cell recording data link them to 'feed backward' neural signaling (i.e. cortical to subcortical or anterior to posterior cortical; Depue & Lenzenweger, 2006; Miller & Buschman, 2012).

Various top-down operations involved in SR engage overlapping and distinct neural regions, underscoring the importance of some differentiation of component functions despite ongoing debate about a possible shared 'core' of top-down processing. A distributed network, parallel, recursive processing model of the brain defies strict localization. However, brain nodes important in top-down processes include the anterior cingulate cortex (ACC; Botvinick & Braver, 2015; Shenhav, Botvinick, & Cohen, 2013); ventromedial prefrontal cortex (Cohen & Lieberman, 2010); ventrolateral prefrontal cortex (Egner, 2011); and the dorsolateral prefrontal cortex (DLPFC; Diamond, 2013). These nodes in turn are embedded in circuits (such as the ACC-DLPFC circuit); the circuits in turn are embedded within distributed functional and anatomical cortical-subcortical networks. Two important networks include the cingulo-opercular and fronto-parietal (Petersen & Posner, 2012). The cingulo-opercular network, broadly, includes the inferior regions in lateral PFC (including ventrolateral PFC), regions of the ACC, the insula, and other nodes. The fronto-parietal network, broadly, involves superior regions in lateral PFC, including dorsolateral PFC, as well as regions of posterior parietal and inferior temporal cortex and subcortical connections. Cross-talk with additional brain networks is important, including the default mode network (which includes the ventromedial PFC) and a noradrenergic, locus-coeruleus 'alertness' network involved in arousal regulation (Aston-Jones & Cohen, 2005, Petersen & Posner, 2012). Subcortical regions, particularly the thalamus and hippocampus, also participate indirectly in top-down regulation via information salience and updating.

Specific conceptual confounds and recommended clarifications

With the preceding in mind, I move on to three key conceptual challenges in the field.

SR and self-control as domain-general

The first issue is the need for a domain-general construct while separating broad and narrower meanings of SR and of self-control. I take SR and self-control together because they are used at times interchangeably (Kelley, Wagner, & Heatherton, 2015; McClelland & Cameron, 2012) to mean top-down control. Matters also have been confused by sometimes conflating *emotion* with *regulation* (so handling an emotionally challenging task = SR) and *cognition* with *control* (so that handling a cognitively challenging task = self-control). I begin by arguing for a domain-general meaning of SR across emotion, action, and cognition (Figure 1).

Emotion regulation is 'any process that influences the onset, offset, magnitude, duration, intensity, or quality of one or more aspects of emotion response' (Gross, 2014). Koole, Van Dillen, and Sheppes (2011) distinguish SR of action (which they call 'SR') from emotion regulation. I take *SR of action* to mean optimization of overt motor, ocular, or vocal response (excluding physiological changes) for purposes of adaptation ('a goal'). Although it is clear that attention (and other cognitive functions) are *regulating* (Posner, Rothbart, Sheese, & Voelker, 2014), some definitions of SR extend it to include cognition as also *regulated* (Karoly, 1993). I agree and use the term SR of *cognition*[3] to connote the modification of attention, memory, or working memory to try to enhance adaptation or achieve a goal in the absence of overt behavior or salient emotion regulation. Counting my breaths to clear my mind is regulating contents of working memory, with secondary regulation of affect; attending to my friend's voice while keeping my eyes on my child is regulating attention; in neither case is there action or primary emotion regulation. These examples are top-down, but when attention is captured by a threat cue, it is regulated by a bottom-up process to enhance survival.

Thus, although some definitions of 'SR' are domain-specific (either distinguishing it from, or else equating it with, regulation of emotion) or narrow (limiting to overcoming temptation), and while it remains important to distinguish SR from the metaskills or component processes that enable it, it is most helpful to treat 'SR' as broader and domain-general (Bell & Calkins, 2012; Blair, Raver, & Finegood, 2016; Karoly, 1993). We can then use specific terms to designate *SR of emotion, action, or cognition*. Note that this is not to postulate a single core process (an empirical question), but that we need an umbrella concept to prevent confusion of domain-specific versus domain-general claims.

Self-control, although it should not be limited to cognition, is a narrower concept. All theorists refer to self-control in relation to top-down process exclusively (Baumeister & Heatherton, 1996; Carver & Scheier, 1982, 2001; Magen & Gross, 2010; Mischel & Shoda, 1995). Common 'narrow' definitions include: (a.1) top-down overcoming of a stimulus-driven response to execute a goal-relevant response (Baumeister & Heatherton, 1996; Diamond, 2013) and more specifically, (a.2) selecting a later, larger reward over an earlier, tempting, but ultimately smaller reward (Rachlin & Green, 1972). However, (b) a broader definition is proposed by others, including (b.1) any deliberate action that promotes long-term adaptation (Fujita, 2011); (b.2) any voluntary alteration of responses (Baumeister, Vohs, & Tice, 2007); or (b.3) voluntary self-governance (Duckworth & Kern, 2011). Such broad definitions effectively simplify *self-control* to the *top-down aspects of SR,* although to avoid confusion, it is essential that researchers spell out, rather than assume or only imply, their intended definition.

Executive functioning, effortful control, and cognitive control are closely related

How do the top-down aspects of SR relate to *executive functioning, EC*, and *cognitive control*, as well as other related terms like *executive attention* and *working memory* (Table 1)? I will argue that EF, EC, and cognitive control are closely related but arise from different intellectual traditions in clinical, developmental, and cognitive sciences.

Executive functioning (EF) or executive functions (EFs). Executive function as a description of top-down cognition emerged from studies of frontal lobe functioning and clinical neuropsychology of adults (Luria, 1966; Pribram, 1973; Shallice, 1982; Shallice & Burgess, 1991; Stuss & Benson, 1986), and was initially operationalized with clinical laboratory measures (Lezak, Howieson, & Lorine, 2004; Strauss, Sherman, & Spreen, 2006). It has accrued a welter of overlapping definitions, as reviewed by Barkley (2012). Contemporary definitions describe (a) a set of at least partially independent top-down functions that support goal-directed action (Banich, 2009; Blair et al., 2016; Diamond, 2013; Friedman & Miyake, 2016; Miyake et al., 2000); or in a computational context, rule-governed behavior (guided by internal goals or rules rather than by external stimuli; Verbruggen et al., 2014); and (b) complex cognition including manipulating two things in mind at once, reasoning, temporal projection, and complex mental and action sequences (Barkley, 1997; Diamond, 2013). EF is invoked when automatized routines will not work or are not possible (e.g. novel situations). Applying the EF concept to young children has been facilitated by child-specific reviews (Diamond, 2013; Garon, Bryson, & Smith, 2008; Jurado & Rosselli, 2007), conceptual models (Diamond, 2013; Wiebe et al., 2011; Zelazo, Carter, Reznick, & Frye, 1997), and measures (Garon et al., 2008; Willoughby & Blair, 2015).

Even pigeons can learn complex behavior chains and carry them out in the face of familiar cues. Humans, however, can assemble a complex sequence of actions based solely on a mental representation, even for novel problems for which automatized behavioral chains cannot be used (unless they are reassembled or remapped to a new context). EF thus allows people both to resolve immediate conflict (e.g. ignoring a distractor), and to manage, in the present, *future* conflicts/goals (e.g. preparing for tomorrow's meeting or next year's marathon).

Because EF is too broad to enable computational implementation or consensus measurement, it must either be operationalized more narrowly or fractionated to be useful for research. Fuster (1997) proposed that the prefrontal cortex supports three basic functions necessary for higher order EF: working memory (which he associated with involvement of DLPFC), set maintenance and shifting ('motor attention'), and inhibition/interference control (suppressing interfering information, which he associated with orbitomedial prefrontal cortex and its connections). In a pioneering empirical report supporting that basic model, Miyake et al. (2000) reported that working memory, response inhibition, and task/set shifting formed three related but distinct latent factors. They did not claim to have used an exhaustive set of EF measures. Subsequently, commonly cited components of EF include response inhibition (stopping a prepotent response), interference control (resisting internal or external attentional distraction), switching (seeing a problem from two different angles as well as changing task set in relation to higher order rule or goal), working memory, planning, fluency, and others (Diamond, 2013; Friedman & Miyake, 2016; Garon et al., 2008; Sharma et al., 2014).

Distinctions among EFs are clearly sensible. In addition to employing partially distinct neural regions, EF component functions develop hierarchically (Rueda, Posner, & Rothbart, 2005). In very young children, EFs hardly extend beyond temporarily overcoming a stimulus-driven response (Garon et al., 2008). Diamond (2013) outlined how key components can be organized developmentally. The earliest to develop she called 'low-level EF': *working memory* and *response inhibition*. These enable a subsequently developing intermediate level, *cognitive flexibility* (which overlaps with set shifting and task shifting). Thus, her lower level and intermediate functions correspond roughly to Fuster's three basic functions. They combine later in development to enable 'high-level EFs', including reasoning, problem-solving, and planning.

EF and emotion: Historically, EF has generally referred to cognitive operations without explicit reference to SR of emotion. However, interest has grown in the role of EF in the SR of emotion, blurring an apparent distinction between cognitive and emotion-related top-down operations. For example, Gross (2014) noted that emotion regulation includes the use of strategies like reframing or proactive planning that clearly rely on EF. Barkley (2012) proposed that EF be defined broadly as any 'self-directed action' aimed at reaching a goal or goal state, effectively equating it with top-down SR. Casey (2015) noted that computationally, emotion is another type of information on which top-down cognition operates. Zelazo and Cunningham (2007) consider EF as directly involved in SR of emotion.

None of those writers, however, intended a full equivalence in regulating emotional and nonemotional information. It is generally recognized that, neurobiologically, while absolute separation of emotion-related from other top-down cognition is problematic, partially distinct neural nodes in the ACC are engaged by top-down regulation in the face of emotionally salient but not cognitively complex conflict (the rostral ACC), versus cognitively complex but not emotionally salient conflict (the caudal ACC; Beckmann, Johansen-Berg, & Rushworth, 2009). Relatedly, the prefrontal cortex can be functionally segregated into dorsal and medial regions (Blumenfeld, Nomura, Gratton, & D'Esposito, 2013; Fuster, 1997) with differential association with emotionally laden tasks. Furthermore, developmentally, the trajectory of behavioral SR differs for emotional and nonemotional stimuli (Botdorf, Rosenbaum, Patrianakos, Steinberg, & Chein, 2016; Casey, 2015; Cohen et al., 2016).

Even so, growing recognition of the overlap and distinction of EF in various SR contexts including emotion has led to new terminology. The most widely used formulation in a developmental context is 'hot' versus 'cool' EF (Zelazo & Carlson, 2012; Zelazo & Muller, 2002). Zelazo and colleagues suggest that these are not two systems but ends of a continuum; in most situations, both are partially involved. *Hot EF* is top-down processing (including regulation) of emotional or incentive signals. It is unclear whether it has any different meaning than top-down SR of emotion – but it serves to emphasize that EFs are involved in regulating emotion. *Cool EF* is top-down processing (including regulation) of salient information signals that have minimal incentive and/or emotional intensity. This distinction does face familiar difficulties, such as different definitions used by different authors, confounding of task with construct, and failure of efforts at psychometric validation (Welsh & Peterson, 2014). Nonetheless, the constructs have been generative and led to new theoretical formulations. For example, Petrovic and Castellanos (2016), while agreeing that the EFs may be domain-general, marshal brain-imaging data to argue that much psychopathology occurs along a neurobiologically mapped hot/cool gradient. For instance, ADHD and conduct disorder may involve breakdown along different parts of that neurobiological gradient.

Summary: Executive functions are interrelated abilities that emerge hierarchically in development, although their precise fractionation varies somewhat across statistical (Miyake et al., 2000), computational (Vandierendonck, 2016), and developmental approaches (Diamond, 2013; Marcovitch & Zelazo, 2009; Wiebe et al., 2011), perhaps in part because components vary with development. EF means the top-down processing of information, including emotion information, and therefore is involved in a domain-general way in all top-down aspects of SR. Consistent with this view, Zelazo and Cunningham (2007) proposed that when the task is SR, then EF is the same as SR. However, that claim depends on agreeing that SR includes top-down *strategies*, such as a priori plans to avoid a conflict in the first place via precommitment (Ainslie, 1975; Fujita, 2011), antecedent regulation (Gross, 1998), implementation intentions, appraisal, construal, and others that are related to SR of emotion (Duckworth, Gendler, & Gross, 2016; Fujita, 2011; Gross, 1998) – because all of these depend on aspects of EF. In other words, when EFs are employed in the service of SR, then EF and SR are practically the same.

Yet, EF should not simply be equated with top-down SR. SR is an adaptive change in internal state, emotion, thought, or action, whereas EF is a set of cognitive capacities that when implemented can enable SR to occur. Crucially, from this perspective, EF is available for purposes *other than* SR. For example, solving a mental math problem requires EF, but is not *self-regulating*.

Cognitive control. Cognitive control is an umbrella term that stands in the EF space within cognitive psychology, although with far less emphasis on complex cognition. It emerged initially in cognitive science as early as the 1960s with the identification of controlled attention as noted earlier (Posner & Snyder, 1975), although only later becoming a defined focus, as reviewed in detail by Botvinick and Cohen (2014). It has been defined recently as 'the ability to flexibly adjust behavior in the context of dynamically changing goals and task demands' (Carter & Krus, 2012, p. 89); as 'a set of superordinate functions that encode and maintain representation of the current task…marshaling to that task subordinate functions including working memory…attention…action selection and inhibition' (Botvinick & Braver, 2015, p. 85); as 'active maintenance of goals and means to achieve them' (Miller & Cohen, 2001); and as real-time optimization of responses (emotion, attention, motor) to a goal (Botvinick & Cohen, 2014). Thus, despite a close relation to EF, cognitive control is narrower than EF with a particular emphasis on resource allocation, information maintenance (working memory), and executive attention, rather than complex cognition (Botvinick & Cohen, 2014; Niendam et al., 2012). Cognitive control can be taken to mean the basic top-down operations from which complex EF emerges.

Conflict is essential to activate cognitive control. It (Table 1) can mean response conflict (two responses have been primed), perceptual conflict (i.e. interference from task-irrelevant information), cognitive conflict (i.e. interference from task-irrelevant associations or thoughts), or goal conflict (task-switching, or a single action will support one goal but defeat another). While highlighted in research on cognitive control, conflict also triggers EF.

Cognitive control is also fractionated in different ways. Proposed elements include executive attention, working memory, response inhibition, and interference control – all overlapping with lower level elements of EF. However, working memory receives considerable emphasis. Proposals using an information processing approach specify other components, such as signal detection, action selection, and action execution.

Summary: For purposes of highlighting integrations, cognitive control is domain-general and is the same as 'low-level' EF as described by Diamond (2013) (possibly including switching). EF depends on cognitive control, but EF extends beyond cognitive control to include complex cognition as well as emotion. Like EF, cognitive control can be employed both for SR and for other purposes; when employed for SR, it is the cognitive part of top-down SR.

Effortful control. The extension of SR to children is heavily influenced by research on temperament pioneered by Rothbart and colleagues (Rothbart, 1981; Rothbart & Derryberry, 1981). SR was seen in a temperament model as comprising the interplay of reactivity (bottom-up) and SR (top-down). Factor analysis of parent ratings of child temperament revealed a higher order factor comprising focusing and shifting of attention, inhibitory control, perceptual sensitivity, and low threshold for pleasure called *effortful control* (Rothbart, Ahadi, Hershey, & Fisher, 2001). Subsequently, Rothbart, Ellis, Rueda, and Posner (2003) offered a more general definition: 'a broad factor involving attentional focusing, attentional shifting, and inhibition and activation control of behavior'…and added that EC is 'the ability to inhibit a dominant response (inhibitory control)…to detect errors…and to engage in planning' (p. 57). They identified correlations between ratings of EC and laboratory measures of attention (orienting and later executive attention) that established a link between EC and brain development (Rothbart, Sheese, & Posner, 2014; Rothbart et al., 2003). Neural implementation was seen as via the ACC-DLPFC circuit and the associated cingulo-opercular network (Posner & Rothbart, 2000, 2007, 2009; Posner et al., 2014). Although EC regulates emotional response, its constituent items include regulation of action and cognition as well. Thus, it is domain-general. EC was also operationalized with laboratory tasks (Eisenberg et al., 2011; Kochanska, Coy, & Murray, 2001; Reed, Pien, & Rothbart, 1984; Rothbart, 2011; Rothbart et al., 2014), some of which overlap with low level EF tasks such as response inhibition.

By its link with basic temperament traits, EC excludes complex cognitions and strategies. Historically, working memory has also been excluded, but Zhou and colleagues (Eisenberg & Zhou, 2016; Zhou et al., 2012) concluded in their literature reviews that working memory is probably part of or closely related to EC. Whether this is due to a shared attention component is unclear. The nascent confirmatory and exploratory factor analytic literature, while complex, generally puts EC and EF trait/task measures, including measures of working memory, on the same factor when measurement type is taken into account (Duckworth & Kern, 2011; Eisenberg & Zhou, 2016; Sulik et al., 2009).

Planning was included as a component of EC in some papers by Rothbart and colleagues, as cited earlier. However, planning entails complex cognition. It is likely that planning is only related to EC due to shared involvement of executive attention and that planning itself goes outside the EC construct (M. Rothbart, personal communication). In short, as identified empirically, EC involves the act of top-down control for purposes of SR, and excludes high-level EF. EC therefore appears to map closely onto low level EF and cognitive control, but at the trait level of analysis.

Summary: Effortful control, identified as top-down aspects of SR, represents at a trait level many of the cognitive control aspects of EF, and in particular executive attention. While empirical examination likely will lead to inclusion of working memory, EC is narrower than EF. While questions remain about precise empirical mapping, careful consideration is warranted for a proposal that EC is a trait level that maps onto the use of cognitive control in SR. It will likely correlate with EF measures of complex cognition, but this would be attributable to their shared dependence on executive attention.

EF, EC, and cognitive control: summary. Executive function, EC, and cognitive control are domain-general in relation to SR of action, emotion, and cognition (although partially distinct neural systems are engaged in those different regulatory contexts). Cognitive control is essentially the same as lower level, or basic EF functions. High-level EFs involve complex cognition and are extended elaborations of cognitive control. Many strategies for SR, such as precommitment, are part of, uses of, or elaborations of EF. EC, while still undergoing empirical investigation of its relations with cognitive control and EF, can be understood provisionally as the trait-level representation of the use of cognitive control for SR.

To reiterate the justification for this, it requires addressing working memory and planning. While in the past omission of working memory from EC made a linkage of EC with cognitive control problematic, and while more empirical work is needed, we can provisionally conclude based on recent empirical work that working memory is part of EC – although it is unclear if this is due to shared involvement of executive attention. At the same time, inclusion of planning in some renditions of EC can be reversed, as EC does not include complex cognition (high-level EF). While EC may be correlated with planning and other complex EF, this is explained by their mutual dependence on executive attention (or, likely, cognitive control generally). This simplification that EC is largely a trait level view of cognitive control, while not without qualifications, enables basic linkage of literatures.

Impulsivity, response disinhibition, and risk-taking should be distinguished

Distinguishing constructs. When SR works well, we successfully navigate response conflict (Table 1) to maximize our adaptiveness (or its mediators – goals, resource gain, and so on). SR can break down in numerous ways. One of the most often mentioned is breakdown in response inhibition ('disinhibition'). Impulsivity and risk-taking are multicomponential behaviors also typically interpreted as breakdowns in SR. Both are often confused with disinhibition. Helpfully, theories of impulsivity and risk-taking have described SR *failures* in a *decision-making* framework. While that is only one of several approaches (Fineberg et al., 2014), the relevant mathematical and computational analyses help describe the SR domain in relation to psychopathology (Nigg & Nagel, 2016; Appendix S1 provides details on the psychophysical basis for this approach as well as its limitations). Avoiding the common muddling of impulsivity, disinhibition, and risk-taking is fundamental to mapping the different ways that SR can break down in psychopathology. (It is also important to relate *compulsivity* to these constructs but space allows me only a brief mention below; see Fineberg et al., 2014, for more discussion).

Response inhibition. Response inhibition is often carelessly used interchangeably with impulsivity. It refers to preventing or interrupting a response – *regardless* of discounting, stimulus valence, or decision context (Aron, Robbins, & Poldrack, 2004; Logan & Cowan, 1984; Nigg, 2000; Simpson et al., 2012; Table 1); it is closely related to inhibition-switch, in which one action is replaced by another. It is an early developing component of top-down aspects of SR (Diamond, 1990, 2013). It is one component of impulsivity and also of compulsivity. In the case of cue-activated automatic behavior, disinhibition and impulsivity are the same. But other cases of impulsivity include discounting of delayed rewards and are not reducible to disinhibition.

Impulsivity. Impulsivity in turn is multicomponential and variously defined, but has two meanings for purposes of this discussion (see Appendix S1 for background on the specifiers given in what follows). One meaning is *nonreflective selection of the stimulus-evoked response* (cue-activated behavior). For example, a frontal lobe patient automatically strikes a match when shown a cigarette, or a dysregulated individual blurts out an unflattering comment upon seeing a friend's weight gain. This type of impulsivity is the same as disinhibition. The other meaning of impulsivity is *nonreflective selection or preference for the immediately rewarding response* (motivated decision style). For example, a drinker despite a resolve to be at work on time, decides to swing by the tavern on the way home (immediate reward prioritized).

Impulsivity in the second instance is more than disinhibition: it also reflects the (implicit as well as explicit) weighting of immediate versus delayed reward. It is modulated both by bottom-up reward valuation (part of the incentive approach system) and top-down biasing related to goals. Notably, *immediate* reward, not merely earlier reward, is what invokes a distinct approach response system (Depue & Lenzenweger, 2006; McClure, Laibson, Loewenstein, & Cohen, 2004; Mitchell et al., 2015). Impulsivity in this context depends on computations involving *time*.

Risk-taking. Risk-taking, in the decision-making context, in contrast entails weighting on *probability* (rather than temporal) features of a choice. It is *the action that discounts the probability of negative consequences relative to probability of positive consequences*. (Appendix S1 discusses other definitions). Either possible reward is excessively valued (computationally, overpredicted) or possible harm is excessively devalued (underpredicted), or both (Casey, 2015; Ernst, 2014). Although risk-taking is clearly related to strong reward motivation (approach in Table 2), its distinguishing feature in fact may be concurrently suppressed estimation of punishment probability. Casey (2015) reviewed animal and human studies indicating that adolescents, while more sensitive to cues for reward and punishment than children or adults, have suppressed sensitivity to punishment context (i.e. ambiguity risk). This may be a bottom-up effect, as animal work she reviewed suggests reduced hippocampal signaling to the amygdala in that context.

Risk-taking can be impulsive (clamoring up a risky cliff face for a view without stopping to think) or reflective (planning an expedition on Mt. Everest). It is risk-taking to the extent that chance of loss is devalued relative to chance of reward. The Everest expedition multiplies one's chances of an early death in return for a thrilling experience. It may be ill-advised, inflexibly chosen, or maladaptive. However, after a year of planning, it is anything but impulsive.

Temporal and probability computations behave differently (Green & Myerson, 2010). One example is the differential *magnitude effect:* when discounting by time, people discount small rewards more steeply than large rewards. But when discounting by probability, the reverse occurs – people discount large rewards more than small rewards (Mitchell & Wilson, 2010). Furthermore, responses in the two experiments are uncorrelated. Impulsivity entails computations about *timing* of outcome (immediate is favored) regardless of *valence* (though research usually focuses on reward). Risk-taking entails computations about *probability,* with relative probability of punishment or loss discounted, regardless of *immediacy*.

Personality theory also distinguishes impulsivity and risk-taking. Eysenck (1993) suggested that two basic personality dimensions were *venturesomeness* and *constraint* (he called it psychoticism, a misnomer in today's nomenclature). In more contemporary work, venturesomeness is related to extraversion and to incentive approach (Table 2), with relative devaluation of uncertainty or possible loss (Sharma et al., 2014), regardless of immediacy. The core theme is psychological movement toward reward (approach), while disregarding potential 'downside' – that is *risk-taking*. *Constraint* entails focusing on long-term payoff and avoiding immediate temptation, among many other low-order facets. It is the inverse of *impulsivity*.

Developmental patterns also differ for impulsivity and risk-taking. Impulsivity declines in linear fashion from childhood to adulthood (Shulman et al., 2016). Risk-taking, in contrast, has a curvilinear pattern, tending (with cultural variation) to peak in adolescence, and decline again in adulthood (Casey, 2015; Mata, Josef, Samanez-Larkin, & Hertwig, 2011). Evolutionary theorists conceive this adolescent risk-taking shift as adaptive for human development (Sercombe, 2014). In support, risk-taking's nonlinear developmental pattern is also quite plastic to environmental context (Mata, Josef, & Hertwig, 2016).

Summary. Table 3 summarizes the contrast between impulsivity and risk-taking across multiple levels of analysis. While readily distinguished in concept and empirically, they can overlap in practice, which is *impulsive risk-taking.* It is recommended that clinical researchers diligently distinguish (a) impulsivity, (b) risk-taking, (c) their overlap, impulsive risk-taking, and (d) inhibition. Furthermore, it is important to articulate whether or not we intend to operationalize a general but not rigid response style/ tendency, versus an *inflexible* response pattern.

Psychopathology and SR breakdowns

Figure 2 schematizes the overlaps and distinctions among these three major instances of faulty SR. It illustrates that while response disinhibition, impulsivity, and risk-taking can certainly overlap, they can also be differentiated in different behaviors or psychopathologies. These distinctions and their overlaps are quite helpful in characterizing the relation of SR to psychopathology. SR aims to serve adaptation ('meet a goal' of state or attainment). Impulsivity, crucially, may be adaptive or not (see Appendix S1 for further discussion). For example, an inflexible impulsive style (immediate decision or reaction, based on immediate stimuli and payoff) may be adaptive for an elite special forces team leader in a combat environment; but then become maladaptive when the soldier returns to civilian life and is needlessly reactive in benign situations (Carey, 2016).[4] The example illustrates that it is misleading to label impulsivity or risk-taking globally as psychopathological or dysregulatory without specifying the context.

Figure 2 notes overlap as well. For example, children with ADHD show both steeper discounting of future rewards (Patros et al., 2016), and riskier style on gambling tasks (Dekkers, Popma, Agelink van Rentergem, Bexkens, & Huizenga, 2016) compared to typically developing children. Thus, *impulsive risk-taking* is risk-taking without reflection, in response to immediate opportunity. It too is often, but not inevitably, maladaptive. *Psychopathological risk-taking* is maladaptive because it is inappropriately impulsive or inflexible.

The distinction between impulsivity and response disinhibition is similarly relevant. Faulty response

Table 3 The distinction between impulsive and risk-taking choice across cognitive neuroscience and personality literatures

	Impulsivity	Risk-taking
Classic personality theory	Impulsivity	Venturesomeness
Current personality theory	Constraint-disinhibition	Extraversion/sensation seeking
Preferred reward choice	Soonest/immediate	Biggest
Computational parameter	Time	Reward size
Devalued parameter	Reward size	Reward/punishment uncertainty
Reflection	No	Neutral (yes or no)
Mathematical function	Temporal discounting	Probability discounting
Magnitude effect reward[a]	Forward (small > large)	Backward (large > small)
Variation across outcomes[b]	Yes	No
Developmental course[c]	Linear	Nonlinear
Heuristic pharmacology[d]	Serotonergic tone	Dopaminergic tone
Metatraits[e]	Stability	Plasticity

For more discussion, see reviews by Green and Myerson (2010) and Evenden (1999). The classic personality model is that of Eysenck (1993); the contemporary rendition is taken from the meta-analysis by Sharma et al. (2014).
[a]Magnitude effect means larger rewards are discounted less steeply than smaller rewards over time ('forward' effect); but more steeply over odds against their occurrence ('backward' effect). If they are governed by the same system then this reversal is puzzling because longer delay is generally correlated with odds against occurrence.
[b]Monetary rewards and consumables (e.g. food) have *different* discounting rates for temporal discounting but the *same* discounting rates for probability (or odds against; Estle, Green, Myerson, & Holt, 2007; Mitchell et al., 2015).
[c]Response control develops with linear growth to adulthood, whereas risk-taking peaks in adolescence and then declines in a nonlinear path (Shulman et al., 2016).
[d]A psychobiological model proposes that Constraint (but not sensation seeking or risk-taking) is related to serotonergic tone (Carver et al., 2009; Depue & Spoont, 1986; Evenden, 1999), while venturesomeness reflects a dopaminergically mediated approach system (Depue and Collins (1999). Neurotransmitter systems involve complex feedback loops that cannot be reduced to a single chemical, but these emphases are heuristic.
[e]For review, see DeYoung (2011).

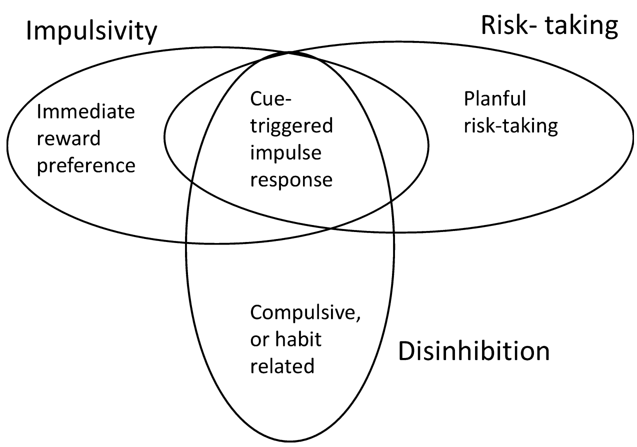

Figure 2 Schematic of the partially differentiable constructs of impulsivity, disinhibition, and risk-taking. Some behaviors represent inhibition as well as impulsivity, but other impulsive behaviors include processes beyond response disinhibition, and some disinhibitory problems are not impulsive (e.g. ruminative obsession). Risk-taking can be impulsive, or not

inhibition is apparent in multiple conditions that are not necessarily impulsive in relation to discounting, for example, anxiety (failure to inhibit response to punishment cue), and habit disorders (e.g. obsessive–compulsive disorder, trichotillomania; Pinto, Steinglass, Greene, Weber, & Simpson, 2014). Compulsive and habit disorders overlap with impulsivity in that they involve breakdowns in response inhibition, but they do not necessarily involve breakdown in delay discounting or in decision preferences for earlier versus later payoffs. Addictions can begin as impulsivity characterized by altered delay discounting, but end as disorders of disinhibition (inability to inhibit response to drink cue). Neurobiology is partially shared in conditions with poor response inhibition (Fineberg et al., 2014). Thus, response inhibition is part of impulsivity but not identical to it; disorders of response inhibition are not necessarily characterized by impulsivity.

Table 4 further summarizes this complex but crucial set of distinctions in relation to psychopathology. Note that impulsivity and risk-taking are only related to failed SR if a modifier is attached, such as 'inflexible'. Deciding to go with the flow at a party may be impulsive without reflecting an SR failure, in that it may lead to adaptive optimization of state to context. It is crucial to clarify, in research and in the clinic, the difference between a behavior (selecting the immediate reward, or selecting the option with the biggest potential downside), and an inflexible application of that behavior. The latter is probably maladaptive on average, but can be adaptive in particular niches or contexts (see Appendix S1 for more discussion of the multilayered issue of specifying adaptiveness; see Block & Block, 1980, for a related perspective).

Integration

Hierarchical integration

A principle of development, and thus of the organization of cognition and personality (response

Table 4 Toward a taxonomy of self-regulation breakdown: Subtypes of impulsivity and risk-taking and relation to response disinhibition

	Low regulation	Maladaptive	Valence trigger	Discounting computation	Response disinhibition
Impulsivity	Maybe	Not necessarily	R	Time	Maybe
Inflexible impulsivity	Yes	Yes (average)	R	Time	Yes
Risk-taking	Maybe	Not necessarily	R/P	Probability	No
Impulsive risk-taking	Yes	Yes (average)	R/P	Both	Yes
GAD	Yes	Yes (average)	P	NA	Maybe
OCD (habit disorders)	Yes	Yes (average)	Specific	NA	Yes

R, Reward; P, Punishment; OCD, obsessive compulsive disorder; GAD, generalized anxiety disorder; time: temporal discounting of future relative to immediate/soon; chance: discounting of probability of punishment relative to probability of reward.
Average = over an infinite number of contexts this response preference would lead to loss of advantage a majority of the time. It may lead to occasional advantage by luck, coincidence, or niche-specific learning.
Spec – the stimulus for OCD and other habit disorders is a *specific* sensation or stimulus that serves as a reward cue; it is specific – that is, not generalized to a response style as in a putative 'impulsive style'. The role of discounting is variable in habit conditions; for example, OCD is associated with normal temporal discounting of reward; on the other hand, drug addiction is associated with steep discounting of future reward.

dispositions) is that it is hierarchical. Development proceeds in a cascade in which subroutines, abilities, or traits combine or share features that can be described in terms of higher order abilities, routines, or traits (Cicchetti & Tucker, 1994; Cox et al., 2010; Masten & Cicchetti, 2010; Smith & Thelen, 2003; Thelen et al., 2001). Computational models feature a similar hierarchical structure for the cross-sectional assembly of SR.

A hierarchical structure is also seen in which nearly all psychopathology shares a general or 'P' factor, while specific components of psychopathology fit into two or more, correlated, low-level domains in adults (Caspi et al., 2014; Lahey et al., 2012) and in children (Noordhof, Krueger, Ormel, Oldehinkel, & Hartman, 2015) in a bifactor structure.[5] These subdomains in turn may also have a bifactor structure (Martel, Roberts, Gremillion, von Eye, & Nigg, 2011) consistent with a cascade in which breakdown in one domain leads to further breakdowns (Martel et al., 2009).

A hierarchical structure also holds for personality and temperament. For example, the 'Big Five' personality traits are correlated into two 'superfactors' labeled in earlier research as avoid and approach but more recently as 'stability' and 'plasticity' (Sharma et al., 2014; Tsukayama, Duckworth, & Kim, 2013). The 'stability' factor comprises low Neuroticism (N), high Conscientiousness (C), and high Agreeableness (A). It is related to Constraint in the three-factor model of personality (Tellegen, 1985).[6] *Plasticity* comprises high Extraversion (E) and Openness to Experience (O) in the big Five framework. Each of the Big Five comprises several psychometrically coherent low-order trait facets. These higher order personality traits appear to assemble hierarchically in development by building on lower order constituents of SR. For example, the trait of Conscientiousness may emerge from earlier development of EC (Eisenberg, Duckworth, Spinrad, & Valiente, 2014) or even earlier from elaboration of sensitivity to negative avoidance signals supporting emergence of EC (Nigg, 2006). It is notable that the hierarchical model of personality appears to be related to the hierarchical model of psychopathology (Tackett et al., 2013).

Updated tripartite model

It is illuminative to convert this picture schematically from a dual-process model to the classic *tripartite model* that has characterized this literature for over a generation, illustrated in Figure 3. This helps us link the bottom-up and top-down conceptions of SR with models of personality and with cognitive neuroscience, and is helpful in bridging literatures.

Panel 3A illustrates the model as described, with variations, by numerous authors (Carver, Johnson, & Joormann, 2009; Depue & Lenzenweger, 2006; Ernst, 2014; Gray, 1982; Nigg, 2006). Two basic bottom-up appetitive processes are emphasized; they are each modulated by top-down control. Either can also interrupt or update top-down processes, thus contributing to (or else disrupting) SR. A gating mechanism allows bottom-up signals to update goal representations.

Panel 3B shows that impulsivity lies at the conjunction of low top-down control and high bottom-up approach (e.g. excitement). Note that approach is related to immediacy valuation in the discounting models discussed earlier. In the other lower quadrant of Panel 3B, low top-down control and low bottom-up approach motivation converge to heighten depression risk (Clark, Watson, & Mineka, 1994). The upper right quadrant of panel 3B (high control, high approach) might represent a tendency for deliberate or planful preference for immediate rewards based on learning history. For example, some youth in dangerous inner city environments appear to adaptively discount the future (Ramos, Victor, Seidl-de-Moura, & Daly, 2013) and as noted, soldiers may learn to make snap decisions as a successful adaptation to frequent combat (Carey, 2016).

Panel 3C illustrates that risk-taking combines low control and low avoidance (e.g. low fear). *Impulsive* risk-taking is likely with low avoidance and low control, provided sufficient approach motivation (thus the small arrow from 3B to 3C). The upper left quadrant of Panel 3C illustrates that low avoidance motivation with strong top-down control might be associated with *planful* risk-taking, as in expert mountain-climbing. While most research has prioritized a focus on the high reward response seen in risk-taking (Shulman et al., 2016), as noted earlier emerging literature suggests that low avoidance motivation (discounting of punishment probability) is associated with risk-taking (Casey, 2015; Van Leijenhorst et al., 2010).

SR: levels of analysis and temporal variation

On a similar principle, the different terms occupying the conceptual space related to top-down aspects of SR are distinguished, in part, by hierarchical variation in specificity, coverage, or granularity, in temporal focus, and in developmental emergence. Their hierarchical arrangement was outlined by Diamond (2013) as alluded to earlier, and suggests that low-level operations like response inhibition and working memory support emergence of more complex operations like higher order EF. Another way of looking at hierarchical integration is to recognize that different aspects of SR differ in their *timescale* (Duckworth & Gross, 2014; Newell, 1990; Verbruggen et al., 2014). Figure 4 illustrates one view of how the domains fit together temporally. Immediate and very short-term conflict requires engagement of response inhibition and working memory (bottom-up regulatory processes are usually immediate, or stimulus-driven[7]). Medium and longer time frames involve high-level EF (strategies and planning) in the face of future conflict or to prepare for future challenge. The long-term future (beyond hours) is largely the domain of higher order EF. Higher order traits of temperament and personality refer to the tendency to utilize the short-term and long-term strategies and describe an individual's typical response bias (e.g. appetitive approach–extraversion; cost-avoidance–neuroticism; exertion of top-down control–EC). Thus, a temporal perspective provides a complementary way of organizing 'lower' and 'higher' order constructs.

Joint integration and recommendations

Table 5 combines the preceding perspectives in a tabular outline format. The developmental illustrations here are only suggestive; more granular

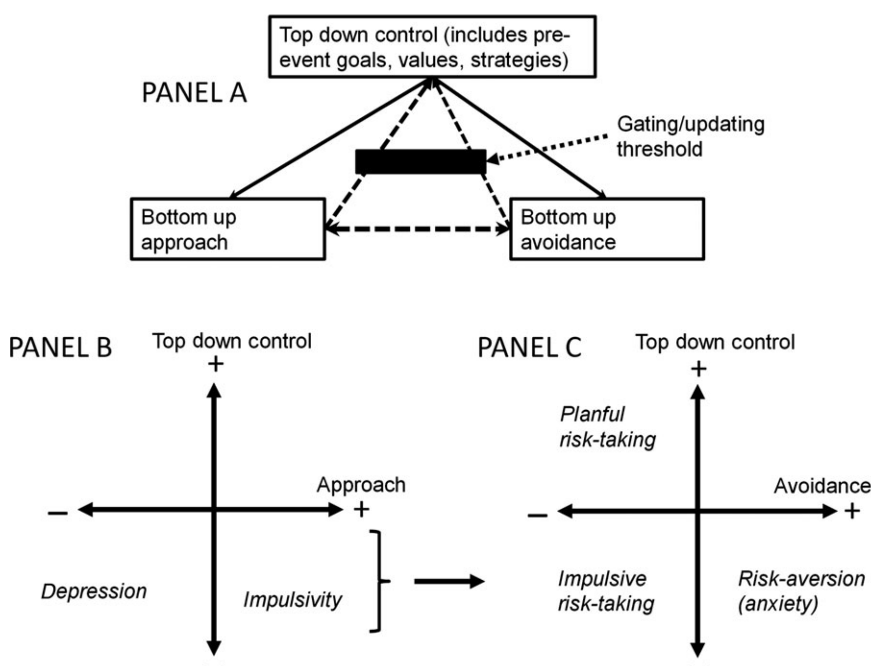

Figure 3 Tripartite model: Figure illustrates the integration of a top-down and bottom-up processes within a model from the psychobiology of personality that parallels what is seen in the cognitive neuroscience and developmental literature. (Panel A) The fundamental tripartite conception. The bidirectional arrows indicate that the two bottom-up systems are mutually regulating, and that both are regulated by top-down control. At the same time, via gating and cybernetic checking mechanisms, the bottom-up processes also regulate the level of top-down control. (Panel B) The interplay of top-down self-regulation (SR) and bottom-up *approach* response creates opportunities for both depression (low top-down capacity and low bottom-up motivation), and for impulsivity (low top-down control with high bottom-up motivation). (Panel C) The interplay of top-down SR processes and bottom-up *avoidance* response (fear/anxiety). Their interplay creates opportunity for anxiety (when avoidance is high and top-down regulatory capacity is low) and impulsive risk-taking (when avoidance is low, top-down control is low, and approach is also elevated – thus the arrow from panel A's lower right quadrant). Panel A is based on material in Carver et al. (2009), Crone, van Duijvenvoorde, and Peper (2016), Hofmann, Friese, and Strack (2009), Gray (1982), Verbruggen et al. (2014) and other sources they cite. Panel B and Panel C are based on material in Nigg (2006) and other sources cited therein [Colour figure can be viewed at wileyonlinelibrary.com]

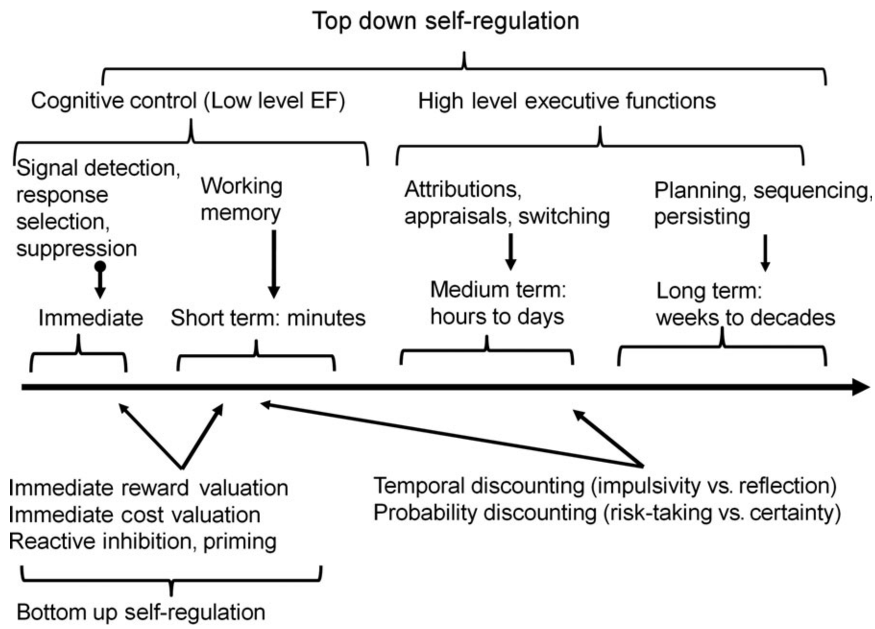

Figure 4 A hierarchical view of different functions involved in self-regulation (SR) this time from the view of time scale of the goal or conflict (immediate or future). Immediate stimuli activate immediate bottom-up valuation mechanisms; their strength is balanced by top-down operations such as response inhibition. Short-term goals are also supported by 'low-level' executive functions (EF) subsumed under cognitive control, such as working memory, but as time spans increase, additional operations are brought to bear to support SR. The examples here are simply illustrative. Bottom-up SR is principally active in immediate and short-term response optimization. Discounting of time and probability effects likely reflects a different combination of bottom-up and top-down processes depending on the species and the particular time frames. The cognitive operations (e.g. lower and higher order EF) can also be employed for purposes other than SR; here only their regulatory application is depicted

discussions of developmental timing of capacities are provided by others (Colombo, 2001; Diamond, 2013; Garon et al., 2008; Huang-Pollock, Carr, & Nigg, 2002; Rothbart, 2011). Here my intent is simply to recall that (a) bottom-up processes emerge and mature earlier than top-down processes and (b) different aspects of SR mature at different rates within both bottom-up and top-down domains. Earlier-developing aspects are part of the assembly of later-developing aspects. Furthermore, the temporal reach of SR increases with development. With these general schematics as support, I move to recommendations for a framework of constructs for use in developmental psychopathology research.

Necessary concepts. I suggest that from the basic concepts listed below, researchers and theoreticians should specify which concept their construct intends to represent or how it is distinct from these basic ideas. Note that this set is not proposed as a formal model – the boundaries between, for example, low-level and high-level EF will be fuzzy, and I already noted that even top-down and bottom-up are not absolute distinctions. This outline is meant as a descriptive framework for linking literatures.

General SR: This should be a domain-general construct that encompasses all SR (including bottom-up aspects). I propose 'self-regulation' here. Within it, particular subdomains can include SR of emotion, of action, and of cognition. This is not meant to propose there is a shared SR process across all forms of SR (that remains a key empirical question). Rather, my intent is to stimulate clarification of the extent of various claims about SR-related processes, determinants, or effects.

Top-down (deliberate) SR: This concept should designate the family of *top-down* SR processes (voluntary or limited-capacity regulation of the self by the self), including both simple processes like response inhibition, and complex processes like preparatory planning to regulate future behavior. It thus includes EC, as well as the SR application of EF. The term 'top-down' has the advantage of being translatable to a conceptual nervous system and schematic computational models. The term 'deliberate' is more easily understood but evades formal definition or computational/neural mapping.

Basic top-down processes (cognitive control and EC but not complex EF): This concept is the lower level, basic, and early developing components of deliberate SR. It is generally congruent with EC and with cognitive control (which can be used for non-SR purposes also), but not with the complex cognition aspect of EF or associated future-oriented strategies. I tentatively suggest that the defining characteristic here be handling immediate challenge or conflict that is represented by an immediate stimulus (a piece of candy in front of me), but not future challenge or conflict that is represented only internally (tomorrow's meeting). Additional fractionation

Table 5 Combined nesting of aspects of self-regulation in level of abstraction/molarity and temporality

	Developmental		Temporal focus
	Emergence	Maturation	
Bottom-up (examples)			
(a) Attentional capture	3 months[a]	Childhood	Immediate
(b) Behavioral inhibition	6 months	Childhood	Immediate
(c) Salience	Unclear	Unclear	Immediate
(d) Immediate valuation	Unclear	Unclear	Immediate
Top-down (examples)			
Low-level EF (cognitive control)			
(i) Res. inhibition	6–9 months	Adolescence	Immediate
(ii) Exec attention	Toddler	Adolescence	Immediate
(iii) WM	Preschool	Adolescence	Immediate
(iv) Delay Reg[b]	Unclear	Adulthood	Both
(v) Risk Reg[b]	Unclear	Adulthood	Both
High level			
(i) Strategies	Toddler	Adulthood	Both
(ii) Sequencing	Preschool	Adulthood	Future
(iii) Planning	Preschool	Adulthood	Future

EF, executive functions; WM, working memory; Reg, regulation; Res, response; Exec, executive.
[a]Developmental onsets and maturation are schematic and arguable. See text. The point here is to illustrate that bottom-up processes emerge and mature earlier than top-down processes and that different components mature at different rates.
[b]Regulation of temporal and probability variation involves both bottom-up valuation mechanisms that are typically quite automatic (and thus behave similarly across species) and control mechanisms that bias those set points in relation to goals in humans.

can be done either in an information processing way to accommodate computational modeling (e.g. signal detection, action selection) or in a behavioral way to accommodate molar behavioral and developmental studies (e.g. response inhibition, response activation, executive attention, working memory) or the components of EC.

Complex cognition and strategies: This concept comprises the *complex* or high-level EF (Diamond, 2013) such as reasoning and planning, and also coping strategies that are adopted strategically or 'intentionally' to self-regulate emotion or action, and which can address future conflict as described by Gross (2015). Complex cognition may be defined as oriented toward future or internally represented conflict or challenge, rather than immediately cued conflict. (Note, therefore that regulatory 'strategies' can refer to both immediate and future conflict, but complex cognition typically addresses future-oriented conflict. For example, a child diverting her attention by looking away from an immediately tempting but forbidden toy is showing a type of strategy, but not using complex cognition.) This high-order domain of *complex* cognition can be further subdivided as needed (e.g. planning, reasoning). Higher order EF is combinations of lower order processes that assemble developmentally as well as behaviorally and computationally. For example, *planning* is an extended application of working memory and action selection; mental flexibility depends on inhibition and working memory; SR coping strategies often entail planning.

Bottom-up or reactive processes: A separate designation is needed for bottom-up processes. These were noted earlier (Table 2). Recall that the involvement of bottom-up (or reactive) processes in SR is complex. It requires consideration of when bottom-up interruption of behavior or cognition is regulating versus regulated, as well as recognition of the ambiguity in differentiating top-down and bottom-up in the SR context. However, particularly important for psychopathology models are the incentive response systems of approach and avoidance. Other systems participate in SR by providing updating information to top-down processes (e.g. associative learning informing working memory in relation to a goal step), as noted earlier. Most important is specification of whether investigators mean to address only top-down SR, or all SR.

Psychopathological breakdowns of SR: A separate domain that overlaps with the preceding is specific to psychopathology, and concerns psychopathological *breakdowns* in SR that emanate from joint involvement of top-down and bottom-up processes. A complete taxonomy of these breakdowns might include problems largely bypassed here, such as compulsive behavior, obsessions, rumination, posttraumatic symptoms, and self-harm – adding constructs only if needed. The first step, highlighted here to start this discussion, is distinguishing between *inflexible* impulsivity (immediate stimulus response), *impulsive* or *inflexible/compulsive* (but not deliberative or calculated) risk-taking, and breakdowns in response inhibition.

Inflexible impulsivity and impulsive risk-taking are not, however, a complete converse of SR, because impulsivity and risk-taking are defined in relation to *decision* contexts. However, SR, including top-down control, is broader than impulsivity or risk-taking, as it refers to state or response *optimization* even when there is no decision context (e.g. shooting a free throw in basketball; hitting the musical note to set the tone for a group to sing; balancing on a bicycle).

Complete set and usage

This set of constructs is proposed as a sufficient descriptive framework for SR (though other components are needed for *process* models of how SR works, such as gating and updating). For description, additional constructs are subcomponents of one of these levels of analysis or refer to their implementation in a particular regulatory or decision context or at a different level of analysis (e.g. neural, cognitive, trait). The considerations in this essay may assist researchers in defining their constructs, and readers in integrating literatures.

These constructs can be used in two ways. One is to help map related constructs across theoretical models and to help in defining what different constructs are represented by a variable. Another is to help in defining targets for study of individual differences, and their correlations, including the structure of the relations among EC and impulsivity, or between top-down and bottom-up forms of control.

Conclusion

Clarifying description and process in the domain of SR is paramount to understanding much of psychopathology. However, progress has been impeded by (a) using separate constructs for regulation of emotion and action without a commensurate domain-general construct that can connect literatures, (b) failing to clearly differentiate top-down and bottom-up contributions to SR, (c) excessive separation of EF, EC, and cognitive control; (d) confounding of impulsivity, disinhibition, and risk-taking; and (e) confounding of constructs across levels of analysis. It is hoped that this essay provides a framework for shared integration across studies and advances our effort to unify knowledge relevant to developmental psychopathology. Future work will continue to refine the neural and physiological concomitants of these processes as well as their mathematical and computational representation. That work can proceed more effectively with a shared terminological roadmap and nomenclature.

Supporting information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Additional reading and background considerations.

Acknowledgements

Work on this paper was supported by grant R37MH59105 by the National Institute of Mental Health. This review was invited by the Editors of this journal, who offered a small honorarium to cover expenses. The author declares that he has no competing or potential conflicts of interest.

The author is indebted for incisive comments on prior drafts of this manuscript to: BJ Casey, Adele Diamond, Nancy Eisenberg, James Gross, Cynthia Huang-Pollock, Sarah Karalunas, Michele Martel, Suzanne Mitchell, Mary Rothbart, Mike Posner, and Laurie Wakschlag. This does not mean any commentators necessarily agree with any particular claims in this paper.

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Key points

- Self-regulation (SR) is of central importance to the field but defined differently across literatures.
- A broad meaning of SR includes top-down and bottom-up processes.
- A close relationship exists between executive functioning, cognitive control, and effortful control.
- Effortful control is hypothesized to be a trait-level mapping of cognitive control.
- Impulsivity, risk-taking, and disinhibition are distinct concepts, but too often conflated.
- Components of SR vary in their developmental assembly and functional time course.
- A limited set of key concepts can help simplify and integrate literatures.

Notes

1. Physiological parameters, such as the cardiac respiratory sinus arrhythmia, as well as hormonal indicators such as cortisol levels, are powerful measures of regulatory process and central to much of that literature (Bell & Calkins, 2012; Calkins & Fox, 2002). They are ignored in this review to constrain its scope; here I focus on the psychological constructs while noting their neural and computational aspects only briefly.
2. An early *connectionist model* included: (a) a top-down 'working memory' mechanism that represents and maintains a goal, (b) a conflict or outcome monitoring mechanism that can influence the level of resource or energy allocated to the control mechanism, and (c) a gating mechanism that allows bottom-up feedback to correct or update the goal representation to enable optimization (Cohen, Dunbar, & McClelland, 1990). Later models recognized that cybernetic (recursive feedback) updating also is accommodated by bottom-up learning mechanisms, which are readily implemented in connectionist architecture (Botvinick & Cohen, 2014) but the basic elements of conflict or outcome monitoring, goal

representation, and gating typically remain. Failures of SR may be due to any of these components. For example, experimental evidence suggests that children with ADHD have poor conflict/outcome monitoring (McLoughlin et al., 2009). *Symbolic models* are a class of computational models that emphasize the nested rule sets and information processing steps in moment-by-moment SR (Wang, Liu, & Fan, 2012); they are underutilized in relation to psychopathology.

3. The idea of cognitive SR is noted in passing by Blair and Razza (2007) in the context of executive functioning but my use here is not widespread.

4. This learned style means something different than a style arrived at by neural injury (e.g. the case of Phineas Gage). In the former case, the 'maladjustment' is created by the change in context and entails difficulty shifting automatized routines to a new learning context. In the case of Gage, it entails a context independent style that was not learned and fails to adapt to any context. A disorder like ADHD is presumed to reflect a developmental, not learned dysfunction that is maladaptive in most contexts. The classic distinction between inherited versus acquired, or between biological versus learned, breaks down on closer examination. At the same time, pursuant to the question of adaptation, psychopathology theory must wrestle with the elusive distinction of attempts at adaptation that fail in a new context (efficient fat storage in an abundant environment leading to obesity; intense vigilance in a violent home leading to relationship breakdown in a safe haven), versus a system overwhelmed and failing (death after excess fever in response to infection; psychosis or chronic unprovoked rage attacks after failed coping with psychological or moral trauma).

5. A bifactor model is mathematically and conceptually distinct from a second-order factor model. (Both are called hierarchical, creating needless confusion). This distinction, crucial for some aspects of psychopathology theory, does not materially alter the current argument related to organizing constructs of self-control as relevant for psychopathology.

6. It is interesting to consider this model in relation to Block and Block (1980) two-factor model of personality. However, Block (1995) objected, noting that these two traits are conceptualized rather differently. In particular, the 'plasticity' trait has rather different connotations in this model than does 'ego resiliency' in the Blocks' model.

7. Bottom-up systems can become chronically activated (anxiety disorders, posttraumatic stress disorder), but they are then not *regulating* but a target of regulation.

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Accepted for publication: 14 October 2016
First published online: 30 December 2016