Cognitive Control Dysfunction and Rehabilitation: Major Theories and Component Process Dysfunction in Traumatic Brain Injury and Psychopathology

Michael J. Larson, PhD
Director, Clinical Cognitive Neuroscience and Neuropsychology Lab
Professor, Department of Psychology and Neuroscience
Brigham Young University
Editor-in-Chief, International Journal of Psychophysiology
Website: cogneuro.byu.edu
Disclosures

Elsevier
I receive an honorarium as Editor-in-Chief of the *International Journal of Psychophysiology*

Clinical Work
Work with Erin Bigler running a clinical neuropsychology practice that also sees forensic cases
Learning Objectives for CE

• The course learning objectives are to help you:

1. Compare the major theories of cognitive control and identify the neuroanatomical correlates of cognitive control processes

2. Identify the primary symptoms of cognitive control component process dysfunction following TBI and in people with psychopathology

3. Explain evidence-based rehabilitation treatments for people experiencing cognitive control dysfunction
Cognitive Control Concept

• Long history:
  • 1910 paper: Ach separated goal-directed (controlled) from automatic processes
  
  • Distinguish between a system responsible for actions that can be considered to be intentional versus more automatic and impulsive/reactive actions
  
  • Automatic versus controlled dichotomy doesn’t fully hold, but there is a top-down, contextually-dependent system relied on for “goal-directed behaviors”

Hommel & Wiers, 2017
What is Cognitive Control?
What is Cognitive Control?

“Ability to guide thought and action in accord with internal intentions”  Cohen, Botvinick & Carter, 2000, p. 421

- Recognize and determine goals
- Direct cognition,
- Identify behaviors and/or mistake
- Adjust performance to accomplish task demands
What is Cognitive Control?

“There is ability to guide thought and action in accord with internal intentions” Cohen, Botvinick & Carter, 2000, p. 421

• **Regulative processes** — Top-down control of cognition
  - Representation of context
  - Preparation to override prepotent response tendencies
  - Broadly mediated by the dIPFC and vIPFC

• **Evaluative processes** — Signal for adjustments in control
  - Conflict detection
  - Performance monitoring
  - Broadly mediated by the ACC
• Cognitive control represents a **subset** of executive functions
  • Highly operationalized based on experimental tasks that isolate **specific** component processes with **specific hypotheses** about neural correlates
    • Regulative processes
    • Evaluative processes

• In contrast, there is often **confusion and controversy** over what executive functions are and how they should be measured
Cognitive Control Lends Itself to Experimental Studies

• Why the need for laboratory investigation?
  • Two important goals of cognitive neuroscience:
    • Specify *component processes* of cognition and their dysfunction
    • Requires experimental control
    • Understand precise *neuroanatomical systems* of function and dysfunction
  • Will aid in development of behavioral and pharmacological treatment strategies

• Limitations of laboratory investigations
  • Experimental control can come at the expense of *ecological validity*
  • Often difficult to map experimental task demands onto “real life” task demands
Learning Objectives #1

1. Compare the major theories of cognitive control and identify the neuroanatomical correlates of cognitive control processes

- **Two main theories we will discuss today:**
  - Conflict Control/Conflict Monitoring Theory of Cognitive Control
    - Cohen, Carter, Botvinick, and others
  - Dual Mechanisms of Control
    - Braver, Barch, and others

- **Note:** There are many other models, these are simply the focus of today (Great review by Hommel & Wiers, 2017 in TICS challenges current views)
Theories of Cognitive Control

Conflict Control/Conflict Monitoring Theory

- **Regulative processes** — Top-down control of cognition
  - Representation of context
  - Preparation to override prepotent response tendencies
  - Broadly mediated by the dIPFC and vIPFC

- **Evaluative processes** — Signal for adjustments in control
  - Conflict detection
  - Performance monitoring
  - Broadly mediated by the ACC
Concept of Conflict

- **Response conflict**: Simultaneous representation of competing response options
  - Simultaneous activation of correct and error responses
  - Example: Incongruent trials on Stroop or Flanker tasks
    - RED, <<<><<, HSHH

- **Stimulus conflict**: Response options are the same, but stimuli are different
  - Example: Modified Flanker or Simon tasks where there are multiple finger mappings, but the response is the same
    - HHSHH, where the H and S both are mapped to the same response
Errors as a Source of Conflict

• In this model, **errors** are also a conflicting response
  • As such, people are continually monitoring their environment and performance for conflict
    • Termed **Performance-Monitoring** and **Environment-Monitoring**

• Event-related potentials (ERPs) useful in studying conflict
  • Temporal precision to identify conflict in stimuli or errors
  • Two examples: the **Error-related Negativity (ERN)** and **N2** components
Error-related Negativity (ERN)

Larson et al., 2007
Localization studies suggest both the ERN and N2 are localized to the ACC

Forster, Carter, Cohen & Cho, 2011
Conflict-Control Loop

ACC & PFC form a feedback loop

Conflict can include errors or simultaneously conflicting information

Context maintenance provides top-down control to improve task performance

Botvinick et al., 2001, Slide adapted from Braver
Let’s Come Back to the Model

Conflict Control/Conflict Monitoring Theory

- **Regulative processes** — Top-down control of cognition
  - Representation of context
  - Preparation to override prepotent response tendencies
  - Broadly mediated by the dlPFC and vIPFC

- **Evaluative processes** — Signal for adjustments in control
  - Conflict detection
  - Performance monitoring
  - Broadly mediated by the ACC
Experimental Control?

• **Recall:** One strength of cognitive control research is the experimental control to test specific component processes:

• Useful task and phenomenon:
  1. Cued-Stroop Task
  2. Conflict Adaptation Effects

• Also known as congruency sequence and sequential trial effects
  • **Note:** There is a lot of controversy regarding priming and conflict here...presenting today in terms of conflict
Single-Trial Cued Stroop

Instruction

Delay

Congruency

“Color”

“Word”

Short (1s)

Long (5s)

Congruent

Neutral

Incongruent

Developed by Cohen, Barch, & Servan-Schreiber, 1999
Dissociable Components
What Does Conflict Signal?

Behavior Change?

• Rabbitt Effect (Post-Error Slowing) (Rabbitt, 1966, 1968)
  • Post-error slowing of RTs following an error
  • Requires both regulative and evaluative control

• Gratton or “Conflict Adaptation” Effects (Gratton et al., 1992)
  • Facilitation of RTs following high- relative to low-conflict trials
  • Present on conflict-laden tasks, such as the Stroop, Flanker, and Simon tasks
    • RTs from fastest to slowest: cC, iC, iI, cI
    • Congruency effects vs. Conflict Adaptation effects
Conflict Adaptation

Figure from Gratton, Coles & Donchin, 1992
Conflict Adaptation Replicated

Clayson & Larson, 2011--Neuropsychologia
Neural Bases

Kerns et al., 2004
Neural Bases

Kerns et al., 2004
More Support: Higher-Order Trial Effects

- Repeated presentation of incongruent or congruent trials can inform us about the biasing of cognitive control functions
  - **Incongruent**
    - Repeated presentation of incongruent trials should minimize conflict on each successive trial
    - That is, increased control = less processing of flanker stimuli
    - Thus, ACC activity should reduce over repeated incongruent presentations
  - **Congruent**
    - Repeated presentation of congruent trials should result in less engagement of cognitive control over time
    - Increased conflict processing when an incongruent trial is presented after many congruent trials

Durston et al., 2003
Higher Order Trial Effects

- MRI BOLD signal in ACC increased as a function of the number congruent trials preceding an incongruent trial (cccl), but decreased with each consecutive incongruent trial (iiil)

Durston et al., 2003
Incongruent Response Times

N2 Amplitude

Congruent Response Times

Clayson & Larson, 2011
Interim Summary

• **Conflict Control Model of Cognitive Control**
  - Dynamic process
  - Predominantly frontal network
  - Anatomically and functionally dissociable component processes
    - dIPFC and vIPFC-mediated regulative control
    - ACC-mediated evaluative control
  - Hopefully, the interaction between these component processes can influence behavior

• Let’s transition to the Dual-Route Model of Control
Braver: Dual-Route Model

- Provides nuance to the conflict-based model
  - **Premise**: Different control processes may be implemented in the same brain regions, rather than separate regions
    - Control processes NOT necessarily *anatomically* distinct
  - **Dissociation**: Occurs based on *temporal characteristics* rather than relying on separate anatomical structures

- Dual Routes:
  - Proactive Control
  - Reactive Control

Braver et al., 2009; Braver, 2012
Braver: Dual-Route Model

- **Proactive Control**—“Early selection”
  - Goal-relevant info sustained in anticipatory manner
  - Occurs prior to cognitively demanding events
  - Biases attention, perception, etc. toward goal completion

- **Reactive control**—“Late correction”
  - Mobilized only when needed
  - Signals after high effort or after high-interference
  - Aids in performance adjustments

- Proactive anticipates and prevents
- Reactive detects and resolves *after*

Braver et al., 2009; Braver, 2012
Braver: Dual-Route Model

- **Both** proactive and reactive rely on PFC network

- **Proactive Control**— sustained dlPFC activity
  - Reflects active maintenance of task goals
  - Top-down bias to improve performance

- **Reactive control**— transient dlPFC (and larger network) activity
  - Bottom-up reactivation of task goals
  - Signal for interference or inattention

- Summary: Dissociation of *anticipatory and sustained* versus *transient and interference-sensitive* PFC activity

Braver et al., 2009; Braver, 2012
Dual-Route Example (from Braver, 2012)

- Asked to pick up something from store on way home from work

  - **Proactive strategy:** Actively sustain goal information until the goal is satisfied (go to store after work)

  - **Reactive strategy:** Goal only transiently activated at time of intention then reactivated with trigger (e.g., text or list)
AX-CPT Task

Time

CUE (Proactive)

TARGET

PROBE (Reactive)

NONTARGET

VALID

“A-X”

“B-Y”

INVALID

“B-X”

“B-Y”

“AY” (70%)

“BX” (10%)

“BY” (10%)

PROBE
AX-CPT Task

Correct response to “X” probe requires memory of previous cue (i.e., proactive)

- Probability distribution creates two biases:
  - Respond to “X” probe as target, even after non-A → BX errors
  - Respond to non-X probe as target following “A” cue → AY errors
  - Often two cue-probe delays: 1s, 5s
  - “BY” trials serve as internal control
  - Longer delay requires active implementation of proactive control, reactive control can be seen on response to probes
AX-CPT & Neuroanatomy

• Many studies published using the AX-CPT paradigm

• One of my favorites showed proactive/reactive dissociation in younger/older adults
Fig. 1. (A) The set of 17 age-related crossover ROIs originally reported in ref. 10. (B) Activation dynamics during trial for younger and older adults (averaged across all ROIs). Older adults show reduced cue-related but increased probe-related activity, associated with a reactive control mode.
Summary: Major Theories and Neuroanatomy

- **Conflict Control theory** suggests a dynamic conflict-control feedback loop
  - Regulative and evaluative control processes

- **Dual-Route of Control model** suggests a more temporal shift depending on task and environmental needs
  - Proactive and reactive control processes

- **Both are instantiated in a PFC-based network**
  - Primarily dlPFC sustained and transient and ACC transient activity
Learning Objectives for CE

• The course learning objectives are to help you:

  1. Compare the major theories of cognitive control and identify the neuroanatomical correlates of cognitive control processes

  2. Identify the primary symptoms of cognitive control component process dysfunction following TBI and in people with psychopathology

  3. Explain evidence-based rehabilitation treatments for people experiencing cognitive control dysfunction
Cognitive Control Dysfunction

- Varies depending on etiology, illness, or trauma

- **Tendencies**: Behavioral impulsivity, poor strategic planning and organization, and failure to accurately perceive and monitor the self- and environment

- **Goal**: Examine specific cognitive control component processes in TBI and psychopathology

- **Participants**:
  - Verified mild, and moderate-to-severe TBI
  - All individuals with TBI 1+ years post-injury
  - All groups well-matched on age and education
As You Know...

- **Moderate-to-Severe (M/S) TBI**
  - Represent approximately 20% of TBI cases
  - Cognitive deficits depend on areas of damage and axonal injury

As You Know...

- **Moderate-to-Severe (M/S) TBI**
  - Represent approximately 20% of TBI cases
  - Cognitive deficits depend on areas of damage and axonal injury

- Damage to prefrontal cortex and related circuitry
  - Generalized slowing
  - Executive dysfunction (problem solving, organization, planning, cognitive flexibility)
  - Cognitive control deficits—Specific component processes?
    - See Scheibel, 2017, for excellent review
Evaluative/Reactive Control

• M/S TBI likely associated with evaluative control dysfunction
  • Animals with ACC lesions make consecutive errors without correction
  • Individuals with medial frontal injuries (axonal shearing; lesion studies) less likely to correct mistakes

• Error-related Negativity (ERN)
  • Event-related potential ~ 50ms after errors
  • ACC implicated as neural generator

Dias & Aggleton, 2000; Swick & Turken, 2002
Cognitive Control: International Neuropsychological Society

Larson et al., 2007
Source Localization (BESA)

Control

TBI

Residual variance = 6%

Residual variance = 18%
More Diffuse Activity?

Sozda, Larson et al., 2011
Awareness?

- Poor error awareness common after M/S TBI

- Dockree and Robertson have several studies showing poor awareness related to daily function and sustained attention

- Poor evaluation/reactive control if an error is unknown or not detected

- Related poor error awareness to ERP activity (Pe)

Dockree et al., 2015; Logan, Hill, & Larson, 2015; Larson & Perlstein, 2009; McAvinue et al., 2005; O’keefe et al., 2004
Evaluative/Reactive Dysfunction Case

Case: Patient BF; 39 y/o female
- Aneurysm rupture of the pericallosal artery
- Specific medial frontal, ACC lesion
  - Poor self- and environment monitoring
    - Staples story—poor awareness
  - Kept trying to get up despite falls and instructions
  - Unresponsive to feedback
- Neuropsychological testing (Wisconsin Card Sort) identified all 3 strategies at 3 points, only answered to one possibility whole time
- Unable to return home; long-term facility
TBI & Cued Stroop: Performance Data

- M/S TBI & Controls not significantly different at short delay
- M/S TBI & Controls significantly different at long delay
- Controls improved at long delay

Seignourel et al., 2005; Perlstein et al., 2006
TBI & Cued Stroop: Performance Data

- Pattern of results suggest that:

- Individuals with M/S TBI show poor *proactive ability to use context* to guide preparation to override a potential pre-potent but inappropriate response (i.e., word reading)

Seignourel et al., 2005; Perlstein et al., 2006
Replication!!

Seignourel et al., 2005; Perlstein et al., 2006; Sozda et al., 2011; Demery et al., unpublished data
AX-CPT Task

CUE (Proactive)

<table>
<thead>
<tr>
<th>VALID</th>
<th>INVALID</th>
</tr>
</thead>
<tbody>
<tr>
<td>“A-X”</td>
<td>“B-X”</td>
</tr>
<tr>
<td>“A-Y”</td>
<td>“B-Y”</td>
</tr>
</tbody>
</table>

PROBE (Reactive)

TARGET

NONTARGET

“BX” (10%)

“AY” (70%)

“BY” (10%)
Proactive Control: AX-CPT

- M/S TBI individuals show
  - Greater AX & BX (proactive control) errors
  - BX > AY errors (not using proactive control, just reacting to the X probe)
  - Similar BY errors by group
    - Error pattern not due to non-specific responding (internal control)
- Mild TBI not different from controls on any condition

AX-CPT Task Error Rates

Larson et al., 2006
TBI & AX-CPT: “Rabbitt Effect”

Controls & mild TBI pts show RT slowing on post-error trials

M/S TBI pts do not show post-error slowing

Suggests, again, that individuals with M/S TBI are not monitoring and/or adjusting strategy to perform task appropriately

Larson et al., 2006; Perlstein et al., unpublished
AX-CPT and Cued-Stroop: Conclusions and Example

- Individuals with M/S, but not mild, show:
  - Poor ability to maintain task instruction context
  - Decreased utilization of context to improve performance

- What might this look like in a case?
  - **Case: JC;** 50+ y/o Security Guard at a mental health facility
  - Worked on same shift for over a decade; was switched to a new unit
  - **Proactive control:** Did not adjust behavior when work context changed
    - Altercations with supervisors and patients
  - Instructions were not maintained and implemented so he reverted to over-practiced/over-trained behavior
Conflict Adaptation in TBI?

- Conflict Adaptation:

![Graph showing mean reaction times (RTs) for Control and TBI groups with congruent and incongruent trials. The graph indicates differences in mean RTs between groups and trial types.](image)

Larson et al., 2009
Evaluative/Regulative Interplay?

- Conflict Adaptation:

![Graph showing Conflict SP Mean Amplitude for Control & TBI](image)

Larson et al., 2009
Similar in Mild TBI

Fig. 2. Mean response times and error rates representing conflict adaptation effects.
Similar in Mild TBI

Larson et al., 2011
fMRI Studies Provide Support

- Scheibel, 2017, Review of Cognitive Control & Neuroimaging in TBI

Concluded:
- Appear to be error-related monitoring difficulties following TBI
- That TBI is often associated with increased/more diffuse activity to accomplish similar behavioral performance
- The increased activity tends to “spill over” into surrounding areas
- Activation increases may reflect a failure to deactivate components of the default mode network (DMN)
Summary: TBI and Cognitive Control

- **Individuals with M/S TBI show evaluative (reactive) control difficulties**
  - Poor conflict/error detection
  - May be tied to error-/performance-awareness
  - Likely reduces ability to adjust behavior leading to similar mistakes “over and over”

- **Individuals with M/S TBI show regulative (proactive) problems**
  - Not a generalized decrement (specific to specific conditions)
  - Tends to be greater at long- than short-delays
  - Likely tied to PFC and cingulate damage and shearing/overcompensation by other areas
Learning Objectives for CE

• The course learning objectives are to help you:
  1. Compare the major theories of cognitive control and identify the neuroanatomical correlates of cognitive control processes
  2. Identify the primary symptoms of cognitive control component process dysfunction following TBI and in people with psychopathology
  3. Explain evidence-based rehabilitation treatments for people experiencing cognitive control dysfunction
Cognitive Control Rehabilitation

- Dissociable cognitive control component processes lend themselves to targeted rehabilitation

- For example, could we exploit individual heterogeneity in disorder presentation to target proactive or reactive control deficits?

- Are there cognitive control component process subtypes that are amenable to specific rehabilitation techniques?

  *Area that is understudied with considerable potential*
Cognitive Control Rehabilitation

- **Honest assessment**: Not a ton out there
  - What is out there has relatively poor evidence

- Included broader construct of Executive Function
  - Focused primarily on TBI and stroke (did not include schizophrenia or MS where there are several more)

- Five relatively recent major reviews:
  - Chung et al., 2013, Executive function rehab Cochrane Review
  - Cicerone et al., 2011 & “under review”, Evidence-based cog rehab
  - Stamenova & Levine, in press, Goal-Management Training meta-analysis
  - Bogdanova et al. 2016, Computerized executive function rehab
  - Reymer et al., in press, Review of systematic reviews of exec rehab
Cognitive rehabilitation for executive dysfunction in adults with stroke or other adult non-progressive acquired brain damage (Review)

Chung CSY, Pollock A, Campbell T, Durward BR, Hagen S
Cochrane Review

- 13 useable studies combined to include 660 participants (395 traumatic brain injury, 234 stroke, 31 other acquired brain injury)

- Only two of the studies (82 people) reported the outcome of interest (a general measure of executive function)

- Concluded: That there was insufficient high-quality evidence to make conclusions regarding exec fxn rehab
  - Need more RCTs with placebo or other improved controls

Chung et al., 2013
Evidence-Based Cognitive Rehabilitation: Updated Review of the Literature From 2003 Through 2008

Keith D. Cicerone, PhD, Donna M. Langenbahn, PhD, Cynthia Braden, MA, CCC-SLP, James F. Malec, PhD, Kathleen Kalmar, PhD, Michael Fraas, PhD, Thomas Felicetti, PhD, Linda Laatsch, PhD, J. Preston Harley, PhD, Thomas Bergquist, PhD, Joanne Azulay, PhD, Joshua Cantor, PhD, Teresa Ashman, PhD
Cicerone et al., 2011

• Levels of Evidence:
  • **Class I evidence:** well-designed, randomized, prospective RCTs
  • **Class II evidence:** prospective, non-randomized cohort studies or case-control or multiple baseline studies
  • **Class III evidence:** Clinical series with concurrent controls or appropriate single-subject methods

• Studies included in the 2011 review for Executive Function rehabilitation:
  • Three Class I, two Class II, and fourteen Class III studies
Cicerone et al., 2011

- Class I studies focused on awareness training and self-monitoring along with an autobiographical memory cueing to help planning
  - I.e., **Meta-cognitive strategy** training had Class I evidence

- Concluded that **meta-cognitive strategy** training is effective for executive remediation
  - **Important**: Including meta-cognitive training for poor self-awareness
Cicerone, “Under Review”

- Data on rehabilitation studies from 2009 to 2014 (used with permission)
- For **executive function**, here are the numbers:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td>Class II</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Class III</td>
<td>11</td>
<td>7</td>
<td>14</td>
<td>19</td>
</tr>
</tbody>
</table>
Cicerone et al., (under review) Findings

• Main points:
  1. Meta-cognitive knowledge ("awareness") and meta-cognitive strategy training (e.g., goal setting, planning, error monitoring) predominated
  2. Meta-cognitive strategy training (MST) continues to have strong evidence and is recommended as a Practice Standard
    • Goal-Management Training (GMT) and Problem-Solving Training (PST) are specifically named as useful components
    • Explicit (verbal and video) performance feedback should be considered with MST as a Practice Guideline
Main points:

3. Indirect Class I evidence supports group-based interventions as a **Practice Option**

4. Severe executive deficits may benefit from skill-specific training including errorless learning, with no expectation of transfer

5. MST as a component of training on functional activities may increase effectiveness of acute rehabilitation after stroke as a **Practice Option**
Example of Meta-Cognitive

- **Goal Management Training** (GMT; Robertson, 1996; Levine et al., 2000)
  - Primary purpose is to help trainees **STOP!** automatic behaviors and identify goal hierarchies
  - Approximately 20 hours of training

- Addresses:
  - Deficit awareness
  - Self-monitoring
  - Regaining control over ADLs

- Process of education, narrative examples, practice, and homework assignments—5 Stages (next slide)
Fig. 1. Flowchart used to illustrate the five steps in goal management training.

Levine et al., 2000
Goal Management Training

• Example from typical Session 2:
  • Goal of Session: **Stop the Automatic Pilot**

• **Steps:**
  • Defining the automatic pilot (habit vs. control)
  • How the automatic pilot can lead to errors
  • Stopping the automatic pilot

• First, provides education about the automatic pilot and how we can make errors when not thinking about tasks

• Sink and U-Bend example (next slide):

Levine et al., 2000, 2011
Automatic Pilot Summary

- Automatic pilot can be very useful for doing routine tasks

- Can be problematic if we don’t check the automatic pilot

- It is difficult to notice when you are in automatic pilot mode
  - Need to stop and think if the activity is helping to accomplish your goals

- Can use the STOP technique to check the automatic pilot

Levine et al., 2000, 2011; http://goalmanagementtraining.weebly.com/
Is GMT Effective?

• Meta-analysis of 21 papers, 19 separate treatment groups (300 total patients)

• Found small-to-moderate effect sizes across several neuropsychological and self- or other-report measures of executive functions
  • Hours trained correlated with several outcomes

• Exception is speed of processing, which showed little change

• Most effects held at follow-up, except self- and other- reports

Stamenova & Levine, in press
Is GMT Effective?

• Study was limited by high heterogeneity

• Sample sizes were quite small

• But, evidence was from many Class I studies

• Overall, appears small-to-moderate gains will be present with GMT-type meta-cognitive compensatory training

• *Class I evidence and useful in MST (Cicerone et al., under review)*
What about computerized interventions?
Computerized Cognitive Rehabilitation of Attention and Executive Function in Acquired Brain Injury: A Systematic Review

Yelena Bogdanova, PhD; Megan K. Yee, MA; Vivian T. Ho, BS; Keith D. Cicerone, PhD
Bogdanova et al., 2016

• 28 studies included (768 participants)

• Only one intervention was used by multiple studies
  • CogMed QM Working Memory Intervention
  • Most studies showed improvements at small-to-moderate levels

• Take-home summary: There is promise for computerized attention and executive rehabilitation **BUT**
Many Limitations

- Only one program was tested in multiple studies
- Only four studies included long-term follow-up data
- Sample sizes and groups were small
- Poor standardization of protocols and outcome measures

Final conclusion: Further research is needed but there is promise
Finally: Raymer et al., in press

Critical appraisal of systematic reviews of executive function treatments in TBI

Anastasia M. Raymer, Jane Roitsch, Rachael Redman, Anne M. P. Michalek
Rachel K. Johnson

- **New:** Summary of the existing reviews and meta-analyses of TBI-related rehabilitation
Raymer et al., in press

- **First Take Home Message**: Over 19 systematic reviews or meta-analyses, concluded that strategy-based (i.e., meta-cognitive) executive function treatments are superior to direct training.

- **Second Take Home Message**: Need more specificity in existing research, including more on:
  - Treatment intensity (e.g., days per week)
  - Treatment duration
  - Dose of training
  - Modality of training (computer, group, etc.)
  - Long-term follow-up
  - Replicability of protocols and details
Exercise?
Acute Exercise

A primer on investigating the after effects of acute bouts of physical activity on cognition

Matthew B. Pontifex\textsuperscript{a,*}, Amanda L. McGowan\textsuperscript{a}, Madison C. Chandler\textsuperscript{a}, Kathryn L. Gwizdala\textsuperscript{a}, Andrew C. Parks\textsuperscript{a}, Kimberly Fenn\textsuperscript{b}, Keita Kamijo\textsuperscript{c}

Psychology of Sport & Exercise 40 (2019) 1–22
Acute Exercise

a) Domains of Cognition

b) Domains of Cognitive Control

Pontifex et al., 2019
Acute Exercise

- Most of these investigations report findings on cognitive control immediately after exercise completion
Acute Exercise

- In 18- to 34-year-old young adults

Pontifex et al., 2019
Acute Exercise

• Acute bout of physical activity on inhibition using the Stroop task show small-to-large reductions in Stroop interference (Cohen’s-d from 0.20 to 1.16)

• Similarly, Flanker RT reductions range from d of 0.20 to 0.95

• Findings suggest improved inhibitory interference control following acute exercise

Pontifex et al., 2019
Acute Exercise

- **Conclusion:** Moderate-to-vigorous intensity exercise lasting 16-to-35 minutes improves inhibitory control in young adult populations (aged 18-to-34 years)

- “Yet, there remains a dearth of literature outside this narrow focus” (page 18)

- “Evidence elucidating the effects of acute bouts of physical activity on other domains of cognitive control and aspects of cognition remains scarce” (page 18)
Long-term “Habitual” Exercise

Review

Relationship between physical activity and cognitive function in apparently healthy young to middle-aged adults: A systematic review

Eka Peng Cox\textsuperscript{a}, Nicholas O’Dwyer\textsuperscript{a,b}, Rebecca Cook\textsuperscript{a}, Melanie Vetter\textsuperscript{a}, Hoi Lun Cheng\textsuperscript{a,c}, Kieron Rooney\textsuperscript{a,d}, Helen O’Connor\textsuperscript{a,d,*}

*Journal of Science and Medicine in Sport 19 (2016) 616–628*
Long-term “Habitual” Exercise

- 12 studies examined executive functions or cognitive control in participants aged 18 to 50

- 7 of 12 (58%) showed significant positive relationships between increased physical activity and improved cognitive control
  - Effect sizes ranged from small to large
  - More vigorous physical activity seemed to drive the findings, suggesting a “fitness” effect
  - Sample sizes likely inadequate for study designs

- Yet...only 12 really solid studies?? More needed

Cox et al., 2016
Summary: Intervention Research

• Lots of potential for specifically addressing cognitive control component processes
  • Little specific research component process intervention

• Executive function rehabilitation in TBI and stroke is supported for meta-cognitive interventions like GMT
  • Computerized interventions may also have support
  • Cochrane review suggests direct measurement needed

• Acute exercise influences inhibitory control processes, there may be promise for longer-term exercise
  • Long-term studies and increased sample diversity and component specificity are needed
Conclusion: Learning Objectives for CE

The course learning objectives were to help you:

1. Compare the major theories of cognitive control and identify the neuroanatomical correlates of cognitive control processes

2. Identify the primary symptoms of cognitive control component process dysfunction following TBI and in people with psychopathology

3. Explain evidence-based rehabilitation treatments for people experiencing cognitive control dysfunction