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Research Article

Verbal initiation, selection, strategy, and inhibition in stroke: A brief executive function screening tool

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Abstract

Objective: Executive dysfunction is prevalent in early stroke and can predict long-term outcomes. Impairments can be subtle and undetected in cognitive stroke screens. To better assess executive functions, this study introduced a novel sentence completion test, which assesses multiple executive processes in <5 minutes (Brief Executive Language Screen – Sentence Completion; BELS-SC). The aim was to determine construct, convergent and divergent validity, sensitivity and specificity of the BELS-SC, and to explore differences between left and right hemisphere stroke patients (LHS and RHS, respectively) on the BELS-SC and standard executive function tests. **Method:** Eighty-eight acute/early sub-acute stroke patients and 116 age-matched healthy controls were included. **Results:** Principal Component Analysis (PCA) suggested four to five factors of the BELS-SC: Initiation, Selection, Inhibition (with strategy loading on Inhibition), Inhibition Response Time, and Semantic Retrieval Response Time. The BELS-SC had good sensitivity (.84) but poorer specificity (.66) differentiating controls and stroke, and good sensitivity (.83) and specificity (.80) differentiating executive function impaired versus executive function intact groups. BELS-SC Initiation and Inhibition subtests demonstrated convergent and divergent validity with corresponding Hayling subtests. LHS and RHS showed impairment across initiation, selection, inhibition and strategy; however, greatest deficits were shown by RHS on Inhibition items requiring suppression of one dominant response. More patients were impaired on BELS-SC than other executive function tests. **Conclusions:** The BELS-SC demonstrated convergent, divergent, and construct validity, good sensitivity and specificity, taps multiple executive processes, and provides insight into strategy. Use in early stroke may aid in targeted and timely cognitive rehabilitation.

Keywords: Executive functions; neuropsychological tests; cognitive screen; acute stroke; sentence completion; Hayling sentence completion test

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Statement of Research Significance

Research Questions:

- This study aimed to investigate the validity, sensitivity, and specificity of the Brief Executive Language Screen – Sentence Completion (BELS-SC) subtest, as a standalone measure of executive functions in an acute to sub-acute stroke sample.
- We investigated whether left and right hemisphere patients performed differently on the BELS-SC.

Main Findings:

- The BELS-SC demonstrated construct, convergent, and divergent validity.
- Sensitivity was good when differentiating stroke patients from controls, and executive function impaired versus intact groups, although specificity was poorer only when classifying stroke patients and controls.
- Although left and right hemisphere groups performed worse than controls on the BELS-SC, the right hemisphere group were particularly impaired on Inhibition.

Study Contributions:

- This study introduces a brief (<5 minutes), executive function screen, which provides insight into multiple executive functions.
- Its use in a stroke population will help inform rehabilitation needs and for more in-depth neuropsychological testing.

Introduction

Executive functions are vital for adaptive and goal-directed behaviors, and everyday activities like driving, behaving appropriately, working, and managing finances (Elliot, 2003; Rabbitt, 1997). Executive dysfunction is common post-stroke, and can predict long-term stroke outcomes, meaning assessment of

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executive functions in acute (1 – 7 days) and early sub-acute (7 days – 3 months) stages is vital for appropriate rehabilitation (Lesniak et al., 2008; Nys et al., 2005, 2007; Pohjasvaara et al., 2002; Veldsman et al., 2020; Wolf, 2011). However, executive functions are typically not comprehensively assessed in an acute stroke setting; thus, deficits can go undetected (Wolf, 2011). This study investigates a brief (< five minutes) novel bedside executive function screen based on sentence completion tests (e.g., Hayling Sentence Completion Test [HSCT]; Burgess & Shallice, 1996) to assess key executive functions (initiation, selection, inhibition, and strategy use).

Initiation

Initiation is required for voluntary generation of verbal and nonverbal (action) responses (Horne et al., 2023; Klaus et al., 2019; Martin et al., 2021; Robert et al., 2018). In clinical settings, verbal (e.g., word fluency) and nonverbal (e.g., Delis–Kaplan Executive Function System Design Fluency Test; Delis, 2001) fluency tasks are frequently used to measure initiation or voluntary response generation (Baldo et al., 2001; Henry & Crawford, 2004; Houston et al., 2005; LaDuke et al., 2018; Pettit et al., 2013; Zhao et al., 2013). Verbal initiation is also frequently captured via sentence completion tasks, which require the quick generation of one word to meaningfully complete a sentence (Bloom & Fischler, 1980; Burgess & Shallice, 1996). Impairment can present as reduced conversational or connected speech, even in patients without frank language disorders (i.e., aphasia: Barker et al., 2017; Costello & Warrington, 1989; Gold et al., 1997; Law et al., 2015; Robinson et al., 1998, 2005; Warren et al., 2003). Verbal initiation deficits and sustained initiation (energization) have been linked to the bilateral frontal regions (Burgess & Shallice, 1996; Robinson et al., 2006, 2015a; Volle et al., 2012) and fronto-medial region, particularly the supplementary motor area (Ardila, 2020; Satoer et al., 2013; Stuss & Alexander, 2007). The supplementary motor area has also been implicated in mutism, suggesting medial prefrontal involvement in initiation processes (Brust et al., 1982; Geranmayeh et al., 2017; Krainik et al., 2003; Nagaratnam et al., 2004).

Selection

Selection is an executive process that involves choosing one response when there are multiple competing ideas available, and is vital in task-setting and decision-making (Brass & von Cramon, 2004; Shallice & Cipolotti, 2018). Converging evidence from lesion (group and single case), neuroimaging and transcranial direct current stimulation studies point towards involvement of the left inferior frontal gyrus (LIFG) in selection processes (Benedek et al., 2014; Costello & Warrington, 1989; Fink et al., 2009; Madden et al., 2019; Moss et al., 2005; Robinson, 2013; Robinson et al., 1998, 2005, 2010, 2016; Schnur et al., 2005, 2009; Thompson-Schill et al., 1997; Zhang et al., 2004). Selection deficits have also been documented in a patient following a left basal ganglia stroke who did not present with aphasia (Crescentini et al., 2008). Together, findings suggest a crucial role of the left posterior frontal region in selection processes.

Inhibition

Inhibition is the ability to purposefully suppress an automatic, prepotent, or dominant response (Aron et al., 2004, 2014; Miyake et al., 2000; Robinson et al., 2015b, 2015c, 2016, 2021). Deficits can manifest as inappropriate behavior, and tangential or unintelligible speech due to an inability to stop the production of off-topic, inappropriate, or irrelevant ideas (e.g., Robinson et al., 2015c). Concerns surrounding whether inhibition tasks truly capture inhibition have been raised, particularly as some tests do not require inhibition to perform well. For example, Aron and colleagues (2004, 2014) have argued that the Stroop Test (Stroop, 1935) captures error detection or interference control, rather than prepotent response inhibition. Further, performance on the Stroop Test can be enhanced by a visual strategy (naming the color of the last letter of each word), meaning the word itself is not processed, which negates the need for inhibition of the automatic response (i.e., to read the word rather than name the color; Aron et al., 2004, 2014; Stuss & Alexander, 2007; Volle et al., 2012). While the HSCT theoretically requires the full meaning of the sentence to be processed, one strategy for providing an unconnected word is to generate an alternate word while ignoring the sentence (e.g., "The captain wanted to stay with the sinking"… "lamp"). True inhibition requires a produced response, before it can be overridden and suppressed (Aron et al., 2014; Friedman & Miyake, 2004; Li et al., 2021; Miyake et al., 2000). For the HSCT, this would require the same sentence to be given in both initiation and suppression conditions, which is not the case.

On verbal and nonverbal inhibition tasks, neuroimaging, lesion and behavioral studies have consistently implicated right posterior frontal regions (Aron et al., 2004, 2014; Cipolotti et al, 2016a, 2016b; Kawashima et al., 1996; Konishi et al., 1998; Robinson et al., 2015b; Volle et al., 2012; Wilson et al., 1998). However, the Stroop and HSCT are behaviorally and anatomically dissociable, with HSCT suppression performance linked to the right lateral prefrontal cortex and left frontal regions, and Stroop performance linked to the left lateral superior, middle, and inferior frontal regions (Cipolotti et al., 2016a, 2016b; George et al., 1994; Moore et al., 2024; Robinson et al., 2015b; Taylor et al., 1997).

Strategy use

Strategy generation and implementation is an executive process that helps to complete tasks efficiently and effectively, which also involves planning and goal evaluation (Burgess & Shallice, 1996; Levine et al., 1998; Robinson et al., 2015b, 2016). Strategy is a critical aspect of neurorehabilitation (Swanton et al., 2020) and thus requires further investigation as a distinct executive process in the context of acute stroke and cognitive assessment (e.g., use of meta-cognitive strategies; Cicerone et al., 2019; McEwen et al., 2019). Strategy is observed on the HSCT, whereby healthy adults typically generate and implement visual and semantic strategies (e.g., looking around the room, items from the same category) to enhance suppression (Burgess & Shallice, 1996; Pluck et al., 2019; Robinson et al., 2015b). To our knowledge, strategy use is not formally assessed or quantified in stroke and therefore under-researched, despite implications for cognitive and functional rehabilitation (Swanton et al., 2020; Van den Broek, 2005). Frontal lesion patients show a reduction in strategy use on the HSCT relative to healthy controls and posterior lesion patients (Burgess & Shallice, 1996). A right lateralization effect for strategy use on the HSCT has also been reported; the proportion of correct strategy-based responses was 11% for right frontal patients, compared to 26% for left, and 29% for healthy controls (Robinson et al., 2015b). This was despite right frontal patients having longer response times (i.e., more time to think of a response/strategy). Findings

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from single case studies also suggest a distinction between strategy generation and implementation (Robinson et al., 2015a, 2016).

Assessment

Fatigue, time, and hospital constraints impact acute stroke cognitive assessment, which means lengthy neuropsychology batteries are not practical. Assessment must be brief and tap domains known to be impacted in stroke (i.e., executive functions). Current stroke screens assess core language, memory, attention, or neglect; however, incorporation of executive functions is either minimal (i.e., one executive process, e.g., switching: Oxford Cognitive Screen [OCS], Demeyere et al., 2015) or absent from these tools (e.g., Quick Aphasia Battery [QAB], Wilson et al., 2018, 2023). Executive functions measured in current stroke screens include switching, problem-solving and goal attainment (Trails and Rule Finding subtests – OCS-Plus; Demeyere et al., 2021), and inhibition/flexibility (Luria Tapping subtest – Cognitive Assessment for Stroke Patients; CASP; Benaim et al., 2022). The BELS Test (Robinson et al., 2021) is a validated cognitive screening test, with high sensitivity (.87) and specificity (.89) for distinguishing stroke patients without aphasia from healthy age-matched controls (Phillips et al., 2024). Its Sentence Completion subtest (BELS-SC) is based on the HSCT (Burgess & Shallice, 1997), and captures executive processes of initiation, selection, inhibition, and strategy. However, it has not yet been introduced or investigated as a standalone bedside executive function screen.

Like the HSCT, the BELS-SC has two parts: Initiation and Inhibition. However, the BELS-SC is novel and distinct from the HSCT in three ways to expand the executive functions measured. The key differences are: 1. *Incorporation of a selection component* in the Initiation section; 2. *Increased inhibition demands* in the Inhibition section; and 3. Introduction of *a strategy score* in the Inhibition section.

Aims

This study aimed to 1) determine construct validity and internal consistency of the BELS-SC via Principal Component Analysis (PCA) and Cronbach's Alpha, 2) determine sensitivity and specificity of the BELS-SC as a standalone test of executive function, 3) establish convergent and divergent validity of the BELS-SC with the HSCT, 4) using known-groups methodology, examine how left and right hemisphere stroke patients performed on the BELS-SC initiation, selection, inhibition and strategy subtests, and other executive function measures (Stroop Interference and Trails). It was hypothesized that 1) PCA would show four components of the BELS-SC (initiation, selection, inhibition, and strategy), 2) the BELS-SC would have high sensitivity (true positives), and specificity (few false positives), 3) the BELS-SC would demonstrate convergent and divergent validity with the HSCT, and 4) overall, both LHS and RHS would perform worse than controls on the BELS-SC and standard executive tests; LHS and RHS would perform similarly on BELS-SC Initiation; LHS would be more impaired on BELS-SC Selection; and RHS would be more impaired on BELS-SC Inhibition and Strategy.

Method

Data was collected for an ongoing project (started in 2017) from stroke units (Princess Alexandra Hospital, Royal Brisbane and Women's Hospital, Surgical Treatment and Rehabilitation Service) by supervised clinical neuropsychology registrars and doctoral candidates (publications to date: Horne et al., 2022; Moore et al., 2024; Phillips et al., 2024). Ethical approval was given by the Metro South and Metro North Queensland Health and the University of Queensland Human Research Ethics Committees (HREC/16/QPAH/793), and research was completed in accordance with the Helsinki Declaration. Informed written consent was obtained from all participants. Data is available on the Open Science Framework (https://osf.io/py6xb/). The data used in this study is part of a larger study and was previously analyzed as part of the global BELS score in a recent publication (Phillips et al., 2024). This is a secondary comprehensive analysis focused on one of 11 BELS subtests.

Participants

Stroke patients

Inclusion criteria for patients were first-time stroke (confirmed by brain imaging), aged 18 or older, and fluent English. Exclusion criteria were Transient Ischemic Attack, or diagnosis of another neurological disorder. Participants who did not complete the BELS-SC subtest were excluded. Reasons for non-completion included fatigue and hospital interruptions. One-hundred-and-nine patients were recruited, with a final sample of 88 stroke patients tested on average 17.39 days post-stroke (43% female; handedness: 90% right, 1% forced right, 9% left; $M_{AGE} = 62.88$, $SD_{AGE} = 14.10$; $M_{EDUCATION} = 12.03$, $SD_{EDUCATION} = 2.71$). There were 80 ischemic stroke patients, eight hemorrhagic patients, 57 RHS, 29 LHS, and two bilateral patients. See Table 1 for stroke patients' demographic and stroke lesion information.

Controls

Inclusion criteria for healthy controls were fluent English speakers aged 18 years or older. Exclusion criteria was any neurological disorder, or impairment ($<5^{th}$ percentile) on more than one neuropsychology test which would meet criteria for mild cognitive impairment or other disorders. Participants were recruited via the University of Queensland networks. The final control group consisted of 116 healthy adults (47% female; handedness: 92% right, 1% right/ambidextrous, 7% left; $M_{AGE} = 63.15$, $SD_{AGE} = 13.52$; $M_{EDUCATION} = 15.12$, $SD_{EDUCATION} = 3.56$).

Measures

The following cognitive domains were assessed via standard neuropsychology tests (administered according to test manuals) to provide a cognitive baseline and characterize the groups: visual perception (Visual Object Spatial Perception: Incomplete Letters; Warrington & James, 1991); premorbid optimal level of function (National Adult Reading Test 2^{nd} Edition; Nelson & Willison, 1991); fluid intelligence (Advanced Progressive Matrices Set 1; Raven, 1965, 1994); naming (Boston Naming Test Short Form; Mack et al., 1992); processing speed and switching/flexibility (Trails Making Test Part A and B; Strauss et al., 2006); inhibition (Victoria Stroop; Spreen & Strauss, 1998; initiation and inhibition (Hayling Sentence Completion Test [HSCT]; Burgess & Shallice, 1996).

Hayling sentence completion test

The HSCT (Burgess & Shallice, 1996) has two parts: Initiation and Inhibition. Like the BELS-SC, items are from Bloom & Fischler (1980). Fifteen initiation items are administered first in which participants must quickly complete a sentence with one word. Initiation is scored via reaction time, rounded down to the nearest second; faster times indicate better performance. A different set of

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Table 1. Stroke patients' demographic descriptive statistics

ID	Age	Sex	Handed	Education	Chronicity	Stroke Type	Stroke Side	Artery	Neuroimaging Summary and Presentation
SP001	50	M	R	12	19	Ischemic	Left	MCA	Frontal lobe
SP004	59	M	R	13	17	Ischemic	Left	PICA	Cerebellum
SP007	28	F	R	16	11	Ischemic	Left	ACA	Frontal lobe
SP009	66	M	R	12	16	Ischemic	Left	PCA (Brainstem)	Basal ganglia & superior temporal
SP012	70	M	R	15	25	Hemorrhagic	Left	MCA	Medial temporal & basal ganglia
SP013	40	F	R	16	48	Ischemic	Left	–	–
SP015	76	F	R	14	26	Ischemic	Left	PCA	Medial occipital lobe
SP016	68	M	R	10	45	Ischemic	Left	PCA	Occipital lobe
SP024	72	F	R	10	21	Ischemic	Left	MCA	Basal ganglia
SP026	86	F	L	8	36.5	Ischemic	Left	MCA	–
SP027	60	M	R	15	21.5	Ischemic	Left	–	Basal ganglia & internal capsules
SP029	59	M	R	16	14	Ischemic	Left	PICA	Cerebellum
SP031	37	M	R	12	9	Ischemic	Left	–	Parietal
SP036	55	F	R	12	31	Ischemic	Left	MCA	Frontoparietal
SP041	51	M	L	10	6	Ischemic	Left	MCA	Frontal, parietal & centrum semiovale
SP043	70	F	R	10	9	Ischemic	Left	PCA	–
SP044	59	M	R	10	6	Ischemic	Left	MCA	Temporal, frontal & parietal
SP050	65	M	R	10	8.5	Ischemic	Left	PCA	Temporal & occipital
SP052	69	M	R	13	12	Ischemic	Left	ICA, MCA	–
SP057	61	M	L	16	8.5	Hemorrhagic	Left	PCA	Occipital intraparenchymal
SP060	48	F	R	12	4	Ischemic	Left	MCA	Frontal
SP072	65	M	R	10	5	Ischemic	Left	Lacunar	Left capsule
SP082	43	F	R	12	2	Ischemic	Left	PCA	Occipital
SP083	91	F	R	12	15	Ischemic	Left	–	–
SP084	74	M	R	9	9	Ischemic	Left	ACA	Frontal
SP097	64	F	R	12	8	Ischemic	Left	Basilar	Medulla
SP100	62	M	R	12	12	Ischemic	Left	Basilar	Medulla
SP103	82	F	R	10	23	Ischemic	Left	Lacunar	Thalamus, parietal, occipital
SP104	78	F	R	10	38	Ischemic	Left	MCA, ICA	Frontal
SP002	74	F	R	10	19	Hemorrhagic	Right	–	Basal ganglia
SP003	69	M	R	16	5	Ischemic	Right	MCA	Caudate, frontal & lentiform
SP005	63	M	R	14	15	Ischemic	Right	PCA	Occipital lobe
SP006	84	F	R	13	16	Ischemic	Right	MCA	Posterior frontal lobe
SP010	54	M	R	15	39	Ischemic	Right	MCA	Basal ganglia & superior temporal
SP011	69	F	L	17	21	Ischemic	Right	MCA	–
SP017	73	F	R	16	46	ischemic	Right	MCA	–
SP019	58	M	R	11	45	Ischemic	Right	PICA	Pontine
SP020	64	M	R	10	26	Ischemic	Right	MCA	Frontal, parietal, insula
SP021	62	M	R	18	30	Ischemic	Right	–	Basal ganglia
SP022	67	M	R	12	9	Ischemic	Right	ICA, MCA	Frontal, temporoparietal
SP025	50	M	R	12	41	Ischemic	Right	ACA	–
SP028	71	M	R	20	26	Hemorrhagic	Right	–	Prefrontal cortex
SP030	86	M	R	11	21	Ischemic	Right	MCA	Posterior frontal & parietal
SP032	68	F	R	16	27	Hemorrhagic	Right	–	Thalamic, basal ganglia
SP033	60	F	R	14	35.5	Ischemic	Right	MCA	Temporal lobe
SP034	55	M	L	12	26	Ischemic	Right	Vertebral V3/V4	Medulla
SP035	81	F	R	10	37	Ischemic	Right	MCA	Temporal & frontoparietal
SP037	41	M	R	12	5	Ischemic	Right	PICA	Cerebellum
SP038	65	F	R	12	32	Ischemic	Right	PICA	Occipital
SP040	57	M	R	18	18	Ischemic	Right	MCA	Parietal
SP042	65	M	R	10	25	Ischemic	Right	MCA	Subcortical, deep white matter
SP045	51	M	L	10	5	Ischemic	Right	MCA	Precentral gyrus
SP046	79	M	R	8	4	Ischemic	Right	MCA	–
SP047	43	M	R	12	6	Ischemic	Right	MCA	Frontal & precentral gyrus
SP048	62	M	R	7	2.5	Ischemic	Right	ACA	Frontal & temporal
SP049	70	F	R	12	6	Ischemic	Right	Lacunar	–
SP051	59	M	R	12	10	Ischemic	Right	Lacunar	–
SP053	45	F	R	11	6	Ischemic	Right	ICA, MCA	–
SP054	61	M	R	10	4	Ischemic	Right	MCA	Frontal
SP055	74	M	R	11	4	Ischemic	Right	MCA	Frontal
SP056	81	M	R	12	8	Ischemic	Right	PCA	Pontine
SP058	76	M	R	12	3	Ischemic	Right	MCA	Frontal
SP059	58	M	R	10	8	Ischemic	Right	MCA	Thalamus
SP063	66	M	R	12	4	Ischemic	Right	MCA	Frontal & temporal
SP064	68	M	R	12	2	Ischemic	Right	ACA	Frontal
SP065	78	F	R	10	5	Ischemic	Right	MCA	–
SP068	74	F	R	10	7	Ischemic	Right	PCA	Cerebellum
SP070	49	M	R	12	38	Ischemic	Right	Lacunar	Thalamus
SP073	47	M	R	14	9	Ischemic	Right	Vertebral/Basilar	Cerebellum
SP074	73	M	R	11	14	Ischemic	Right	Lacunar	Internal Capsule
SP075	86	F	R	7	4	Hemorrhagic	Right	ACA/MCA	Basal ganglia
SP076	41	F	R	16	4	Ischemic	Right	MCA	Frontal & insula
SP079	75	M	R	9	2	Ischemic	Right	ICA	Cerebellum

(*Continued*)

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Table 1. (*Continued*)

ID	Age	Sex	Handed	Education	Chronicity	Stroke Type	Stroke Side	Artery	Neuroimaging Summary and Presentation
SP080	62	F	R	9	5	Ischemic	Right	Lacunar	Frontal
SP085	69	F	R	12	49	Ischemic	Right	MCA	Frontal, temporal & putamen
SP088	64	M	R	9	32	Ischemic	Right	Lacunar	Basal ganglia & internal capsule
SP089	60	M	R	10	34	Ischemic	Right	ICA, MCA	Frontal, temporal, parietal & basal ganglia
SP096	73	F	R	12	4	Ischemic	Right	MCA	Frontal & insula
SP098	68	F	R	10	2	Ischemic	Right	MCA	Frontal & basal ganglia
SP099	60	F	R	12	3	Ischemic	Right	MCA	Temporoparietal, frontal, basal ganglia
SP101	41	F	R	18	6	Ischemic	Right	ICA	–
SP102	59	F	R	10	18	Ischemic	Right	Basilar	Mid brain, pons
SP105	72	M	R	9	15	Ischemic	Right	ICA, MCA	Frontal & temporal
SP106	73	F	R	12	32	Ischemic	Right	Basilar	Temporal
SP107	18	F	R	12	40	Hemorrhagic	Right	ACA	Frontal
SP109	52	F	R	17	45	Hemorrhagic	Right	Basilar	Basal ganglia
SP066	79	M	L	7	9	Ischemic	Bilateral	MCA/ACA	Occipital & basal ganglia
SP078	23	F	R	12	10	Ischemic	Bilateral	MCA	Parietal, sagittal sinus

Note: SP002 – "Small Vessel" (Basil Ganglia – lacunar?); SP013 – "NA" (but thalamic – Lacunar?); SP022 – MCA (secondary to ICA occlusion); SP089 – MCA (secondary to ICA dissection). Chronicity refers to number of days post-stroke.

fifteen items are then administered for Inhibition. Participants must quickly produce a word completely unconnected to the sentence. Inhibition is scored via reaction time rounded down to the nearest second (faster times indicate better performance), and accuracy (higher scores indicate better performance). Inhibition errors are classified as either blatant ("The captain wanted to stay with the sinking . . . 'ship'") or partially connected ("The captain wanted to stay with the sinking . . . 'car'").

BELS-SC

The BELS-SC takes up to five minutes to complete. Items, like the HSCT, were drawn from Bloom & Fischler (1980). See Supplementary Materials for BELS-SC stimuli and scoring and Phillips and colleagues (2024) for BELS administration and scoring instructions.

Part one: initiation

The initiation condition (ten items) is administered first and requires

participants to meaningfully complete a sentence with one word as quickly as possible (e.g., "I could not remember his" . . . "name"). ***Selection*** was incorporated by including five high constraint (HC; low selection) items, and five low constraint (LC; high selection) items in the Initiation section. HC sentences have one or few dominant responses, whereas LC sentences have multiple competing responses (Bloom and Fischler, 1980). An example of an HC sentence is: "The paint turned out to be the wrong . . . ," where "color" is the dominant response. In contrast, the LC sentence "The Smiths had never visited that . . . ," can elicit multiple responses (e.g., "city," "country," "town," "neighborhood," "museum," "park," "beach"). Selection demands are low for HC sentences but high for LC sentences because multiple competing response options require a selection process to preferentially choose one word that will be produced (Robinson et al., 2005, 2021). Initiation is captured predominantly via response times (time between end of stimuli presentation and when participant begins response; Burgess & Shallice, 1996). However, selection impairments can either manifest as a failure to produce a word (e.g., in severe cases – Robinson et al., 1998; 2005; 2013) or as disproportionately long response times for LC compared to HC items (e.g., in healthy aging – Barker et al., 2022). Responses on the Initiation section are scored on both accuracy (one-two word answer, response within 20 s, and word meaningfully completes sentence), and response time to two decimal places. A total weighted score out of 10 for BELS-SC Initiation incorporates both reaction times and accuracy (i.e., 2 points for accuracy, 4 points for HC reaction time, 4 points for LC reaction time). See Supplementary Materials for reaction time score cut-offs.

Part two: inhibition

The ten Initiation sentence items are readministered for the Inhibition section; however, participants are required to produce a word completely unconnected to the sentence (e.g., "The paint turned out to be the wrong" . . . "running"). Readministering the same Initiation items was implemented to increase inhibition demands. This is a key difference from the HSCT, which has different items for Inhibition. On the BELS-SC, the participant has already produced a meaningful word to each sentence (i.e., they have processed the semantic context, lexical items, and grammatical structure of the sentence) immediately prior to having to suppress and override each specific response. For example, "They sat together without speaking a single . . . " "word," where "word" must then be suppressed in the Inhibition condition. This was based on the notion that an initial response must be elicited, for subsequent suppression of that response to occur (Aron et al., 2014; Friedman & Miyake, 2004; Li et al., 2021; Miyake et al., 2000). Performance on BELS-SC Inhibition was captured via accuracy and scored out of ten (see Table 2 for types of errors). ***Strategy***. The BELS-SC extends upon the HSCT by incorporating a score out of two to reflect the number of instances of visual and/or semantic strategy use. An example of a visual strategy is naming things around the room, or a semantic strategy may involve naming animals or multiple items from a semantic category (e.g., fruits, colors, furniture, types of trees). A score of zero is given for no instances of strategy use; a score of one is given for one to two instances of strategy use; and a score of two is given to three or more instances of strategy use. For example, if for five items a participant named an object in the room, that would count for 5 instances of strategy use and be awarded a score of two. A total possible score of 22 can be achieved on the BELS-SC (ten points for Initiation/Selection, ten points for Inhibition, and two points for strategy), with higher scores reflecting better performance.

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Table 2. Examples of BELS-SC inhibition errors

	Connected errors	Partially connected errors		
BELS-SC item example	A	B2	B3	B4
The paint turned out to be the wrong . . .	*Color*	*Red Blue*	*Tin Right*	*Taste*
The Smiths had never visited that . . .	*Beach*	*Sand*	*Holiday Browns*	*Planet*

Note: A Error = blatant (sentence is meaningful). B2 Error = response is semantic or opposite to the "meaningful" A response. B3 Error = response is semantic to the sentence. B4 Error = response is bizarre.

Analyses

IBM SPSS Statistics 27 was used for all analyses. An alpha of .05 was set for analyses, except when Bonferroni corrections were applied for multiple comparisons (as stated in Table notes). Three PCAs were conducted to determine construct validity, followed by Cronbach's Alpha to assess internal consistency of PCA factors and individual BELS-SC items. Next, a series of Receiver Operating Characteristic (ROC) curve analyses were performed to determine sensitivity and specificity of a cut-off score on the BELS-SC when a) distinguishing stroke patients from controls, and b) distinguishing participants who were impaired and intact on standard measures of executive functions. Bivariate Pearson's (and Kendall's Tau) correlations were used to determine relationships between BELS, HSCT, and Stroop tests. Outliers more than three standard deviations above or below the mean were removed and log transformations were performed on Initiation reaction time variables. To determine differences between healthy controls, LHS, and RHS on BELS-SC subtests, as well as on standard neuropsychology tests non-parametric tests were used (Kruskal-Wallis and Mann Whitney U), due to data not meeting assumptions of normality. Following data transformation, assumptions of normality remained unmet, and it was not possible to control for demographic differences (education) using parametric analyses. Due to the broad spectrum of stroke and lower education being one risk factor (McHutchison et al., 2017; Yusuf et al., 2020), it was important to retain a broad range of controls. Thus, like other stroke cognitive screening validation studies (OCS – Demeyere et al., 2015; QAB – Wilson et al., 2018), our stroke group had fewer years of education than controls. However, we provide a supplementary analysis that subsampled 70 healthy controls selected to be age *and* education matched to stroke patients (Borne et al., 2024; Kover & Atwood, 2013; Mervis & John, 2008).

Results

Descriptive statistics for baseline neuropsychology measures and BELS-SC subtests for controls and LHS and RHS stroke groups are reported in Table 3 (see Supplementary Table 1 for whole stroke group descriptive statistics). Patient groups were matched on education, number of days assessed post-stroke (U = 756.50, p = .522), and all baseline neuropsychology tests (See Supplementary Table 2). All groups were matched in age, visual perception, and inhibition/switching (Stroop Error Percentile and Interference). Controls had three years more education than patients and performed significantly better than patient groups on premorbid and fluid intelligence, naming, and processing speed. Controls also performed significantly better than LHS on Trails Switching.

On the HSCT, control, LHS, and RHS groups did not differ significantly on Initiation, partially connected errors, or semantic strategies (see Supplementary Table 2 for HSCT whole stroke group comparison statistics). On all other HSCT variables, controls performed significantly better than RHS, and patient groups did not differ significantly. Controls only performed significantly better than LHS on C7 strategies (semantic *and* visual). For age and education comparisons, there were minor changes (for details, see Supplementary Table 3). For clinical scaled scores (SS), patients were mostly intact for Initiation reaction time (1 LHS and 1 RHS impaired, i.e., <5th percentile), compared to 33% of patients impaired on Inhibition errors (24% of LHS; 40% of RHS).

Fewer patients were impaired on Stroop Interference and Trails Switching than on the BELS-SC, with a greater proportion of LHS than RHS performing below the 5th percentile. The proportion of LHS and RHS impaired on HSCT Initiation and Inhibition reaction time scaled scores were similar; however, a greater proportion of RHS were impaired on Inhibition error scaled scores.

Construct validity

Three PCAs were conducted: 1) whole group, 2) patients only, and 3) controls only (see Tables 4, 5, and 6, respectively). The following variables were entered into the PCAs and considered appropriate: BELS-SC Initiation (HC and LC correct, HC and LC reaction times); Inhibition (HC and LC correct, HC and LC reaction times); and strategy scores. PCAs for the whole group and stroke group, revealed four components with eigenvalues > .70, accounting for 82.2% and 83.2% of the total variance, respectively, and the scree plot also suggested four components (Cattell, 1966; Joliffe, 1972, 1986). PCA with controls revealed five components, which accounted for 79.19% of the total variance. Tables 4, 5, and 6 show factor loadings after Oblimin rotation and internal consistencies for each factor.

For the whole group (PCA 1: Table 4) and stroke (PCA 2: Table 5) PCAs, the clusters of items that loaded on each component were the same (but were weighted differently). For PCA 1, Component 1 reflects Inhibition, Component 2 reflects Initiation, Component 3 reflects Inhibition Response Time, and Component 4 reflects Selection. Components 1-4 for the stroke only group (PCA 2) were Selection, Inhibition, Inhibition Response Time, and Initiation, respectively. For controls only (PCA 3: Table 6), the Inhibition, Initiation, and Inhibition Response Time components were the same; however, there were two key differences: 1) Initiation LC reaction time did not load on the Selection Component, and 2) there was an additional Semantic Retrieval Response Time Component (with Initiation LC and HC reaction times loading together).

The BELS-SC Inhibition component had high internal consistency across PCAs 1 and 2, but questionable internal consistency for PCA 3 with controls (Cronbach's α = .86, .87, and .65, respectively). Internal Consistency for Inhibition Response Times was high across all three PCAs (Cronbach's α = .86, .86, and .74, respectively). Initiation and Selection internal consistencies were unable to be calculated due to a negative average covariance between variables (i.e., reaction time and total correct measured on

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Table 3. Descriptive statistics for controls and stroke patients (demographic, neuropsychology baseline, BELS-SC)

	Controls				Stroke						
					LHS			RHS			
	N	*M* (*SD*)	*5th % ile*	*Range*	*N*	*M* (*SD*)	*Range*	*N*	*M* (*SD*)	*Range*	*% patients <5th (n LHS: n RHS: n Bilateral)*
Age	116	63.15 (13.52)	–	18.00 – 88.00	29	62.34 (14.55)	28.00 – 91.00	57	63.56 (13.01)	18.00 – 86.00	–
Education	116	15.12 (3.56)	–	9.00 – 25.00	29	**12.03 (2.31)**	8.00 – 16.00	57	**12.12 (2.87)**	7.00 – 20.00	–
[1]Estimated NART IQ	112	110.87 (6.53)	–	92.00 – 123.00	27	**104.22 (5.81)**	92.00 – 115.00	54	**105.59 (7.69)**	85.00 – 123.00	–
Days since stroke			–		29	17.45 (12.36)	2.00 – 48.00	57	17.63 (14.57)	2.00 – 49.00	–
Gender (%F)	116	47%	–	–	29	45%	–	57	42%	–	–
Handedness (%R)	116	92%	–	–	29	90%	–	57	93%	–	–
Stroke type (%Ischemic)	–	–	–	–	29	93%	–	57	90%	–	–
Neuropsychology baseline											
[2]VOSP Incomplete letters /20	102	19.57 (0.65)	–	17.00 –20.00	29	19.48 (0.74)	17.00 – 20.00	54	19.31 (0.95)	16.00 – 20.00	1% (0:1:0)
[3]APM /12	104	8.81 (1.90)	–	3.00 – 12.00	28	**6.93 (3.27)**	0.00 – 11.00	53	**5.79 (2.87)**	0.00 – 12.00	17% (4:9:1)
[4]BNT /15	47	14.34 (0.89)	–	11.00 – 15.00	28	**13.11 (2.47)**	6.00 – 15.00	49	**13.45 (1.78)**	5.00 – 15.00	14% (6:5:0)
[5]Trails A RT	90	29.48 (8.91)	–	13.59- – 55.06	26	**52.17 (51.70)**	18.06 – 281.00	50	**55.93 (33.91)**	17.75 – 153.00	26% (4:15:1)
Trails switching	90	2.43 (1.04)	4.03	1.18 – 7.75	25	**3.25 (1.51)**	1.03 – 7.60	48	2.64 (0.80)	1.28 – 4.33	14% (6:4:0)
[6]Victoria stroop interference	103	2.16 (0.65)	–	1.27 – 5.00	26	2.35 (1.13)	0.98 – 5.22	49	2.29 (0.71)	1.21 – 5.12	5% (3:1:0)
Victoria stroop CW percentile	103	74.47 (34.72)	–	2.00 – 100.00	24	57.58 (41.62)	2.00 – 100.00	47	57.23 (40.53)	2.00 – 100.00	18% (5:8:0)
[7]Hayling Sentence Completion Test											
Overall scaled score (SS)	80	5.68 (1.23)	<3	1.00 – 9.00	24	**4.54 (1.93)**	1.00 – 7.00	42	**3.95 (1.82)**	1.00 –6.00	22% (4:11:0)
Initiation											
Initiation SS	80	5.80 (0.68)	<3	3.00 – 7.00	24	**5.08 (1.44)**	1.00-7.00	43	**5.09 (1.27)**	1.00 –6.00	3% (1:1:0)
Initiation RT	74	13.67 (5.77)	>23.29	5.25 – 32.63	24	26.96 (41.12)	6.50 – 210.82	43	20.86 (16.08)	7.40 – 97.37	26% (6:12:0)
Initiation /15	79	14.77 (0.53)	<13	13.00-15.00	24	14.25 (1.60)	8.00 – 15.00	42	14.64 (0.62)	13.00 – 15.00	6% (3:1:0)
Inhibition											
Inhibition RT SS	80	5.60 (1.00)	<3	1.00 – 8.00	25	4.84 (1.86)	1.00 – 6.00	43	**4.53 (1.79)**	1.00 – 6.00	16% (4:7:0)
Inhibition Errors SS	80	5.99 (1.85)	<3	2.00 – 8.00	25	4.96 (2.46)	1.00 – 8.00	43	**4.00 (2.45)**	1.00 – 8.00	33% (6:17:0)
Inhibition /15	79	11.66 (2.94)	<6	3.00 – 15.00	25	9.56 (4.01)	1.00 – 15.00	43	**7.98 (4.40)**	0.00 – 15.00	28% (5:14:0)
Errors											
A: Connected	79	0.92 (1.38)	>3	0.00 – 8.00	25	1.76 (2.91)	1.00 – 15.00	43	**3.60 (4.23)**	0.00 – 14.00	29% (5:15:0)
B: Partially Connected	79	2.42 (2.26)	>7	0.00 – 9.00	25	3.44 (1.85)	0.00 – 7.00	43	3.33 (2.28)	0.00 – 10.00	3 (0:2:0)
Strategy											
C5: Visual	79	4.72 (3.51)	0	0.00 – 13.00	25	3.24 (3.71)	0.00 – 11.00	43	**2.12 (2.28)**	0.00 – 8.00	38% (10:16:0)
C6: Semantic	79	1.72 (1.45)	0	0.00 – 7.00	25	1.44 (2.55)	0.00 – 12.00	43	1.49 (2.00)	0.00 – 7.00	46% (11:19:1)
C7: Visual and semantic	79	1.27 (1.53)	0	0.00 – 6.00	25	**0.28 (0.89)**	0.00 – 4.00	43	**0.70 (1.34)**	0.00 – 7.00	74% (22:28:0)
Prop. correct with strategy	79	0.64 (0.24)	<0.22	0.22 – 1.00	25	0.48 (0.32)	0.00 – 1.00	41	**0.46 (0.27)**	0.00 – 1.00	22% (7:8:0)
BELS Sentence Completion											
Initiation											
Initiation high constraint /5	116	4.99 (0.09)	<5	4.00 – 5.00	29	5.00 (0.00)	5.00 – 5.00	57	4.93 (0.26)	4.00 – 5.00	3% (0:3:0)
Initiation high constraint RT	109	2.87 (1.22)	>6.22	1.22 – 6.55	29	3.95 (2.43)	1.67 – 11.42	57	**5.09 (4.99)**	1.18 – 27.56	22% (5:13:1)
Selection											
Initiation low constraint /5	116	4.77 (0.44)	<4	3.00 – 5.00	29	**4.38 (0.82)**	2.00 – 5.00	57	**4.47 (0.73)**	2.00 – 5.00	9% (3:5:0)
Initiation low constraint RT	109	9.29 (5.21)	>18.90	2.89 – 34.00	29	**15.95 (10.10)**	6.10 – 57.20	57	**14.89 (11.63)**	3.85 – 59.72	19% (6:10:1)
Initiation (Weighted) /10	109	9.22 (1.56)	<5.90	2.00 – 10.00	29	**7.60 (2.73)**	1.80 – 10.00	57	**7.56 (2.93)**	1.40 – 10.00	28% (9:15:1)

(*Continued*)

Table 3. (*Continued*)

	Controls				Stroke						
					LHS			RHS			
	N	*M* (*SD*)	5^{th} % *ile*	*Range*	*N*	*M* (*SD*)	*Range*	*N*	*M* (*SD*)	*Range*	% *patients* $<5^{th}$ (*n LHS: n RHS: n Bilateral*)
Inhibition											
Inhibition high constraint /5	115	4.22 (0.88)	<2.80	1.00 – 5.00	29	**3.10 (1.50)**	0.00 – 5.00	55	***1.87 (1.63)***	0.00 – 5.00	49% (8:33:1)
Inhibition low constraint /5	115	3.79 (1.27)	<1	1.00 – 5.00	29	**2.55 (1.88)**	0.00 – 5.00	55	**1.65 (1.54)**	0.00 – 5.00	27% (5:17:1)
Errors											
A: Connected	112	0.34 (0.58)	>2	0.00 –2.00	29	1.38 (2.44)	0.00 – 10.00	55	***2.76 (2.75)***	0.00 – 10.00	38% (5:27:1)
B: Partially connected	112	1.66 (1.51)	>5	0.00 – 6.00	29	**2.62 (1.88)**	0.00 – 6.00	55	**3.40 (1.94)**	0.00 – 7.00	15% (3:9:1)
Strategy											
Strategy /2	115	1.82 (0.45)	<1	0.00 – 2.00	29	**1.24 (0.87)**	0.00 – 2.00	55	**0.89 (0.81)**	0.00 – 2.00	36% (8:21:2)
C5: Visual	115	3.00 (2.26)	0	0.00 – 8.00	29	**1.59 (2.31)**	0.00 – 9.00	55	**0.85 (1.74)**	0.00 – 10.00	58% (16:32:2)
C6: Semantic	115	1.04 (1.25)	0	0.00 – 6.00	29	1.21 (1.45)	0.00 – 5.00	55	***0.45 (0.86)***	0.00 – 5.00	63% (13:39:2)
C7: Visual & Semantic	115	0.77 (1.39)	0	0.00 – 7.00	29	**0.10 (0.41)**	0.00 – 2.00	55	**0.13 (0.39)**	0.00 – 2.00	90% (26:49:2)
Prop. correct with strategy	114	0.61 (0.26)	<0.16	0.00 – 1.00	27	0.46 (0.33)	0.00 – 1.00	45	0.46 (0.38)	0.00 – 1.00	29% (7:13:1)
Sentence Completion /22	108	19.17 (2.39)	<15	13.00 – 22.00	29	**14.50 (4.83)**	5.40 – 21.80	55	**12.05 (5.61)**	1.60 – 22.00	57% (13:34:2)

Note: RT = "reaction times" in seconds. HSCT and BELS "Proportion Correct with Strategy" has missing data due to some participants scoring 0 correct. Bolded M(SD) indicates significant difference from controls. Bolded and italicized M(SD) indicates significant difference between patient groups. [1]National Adult Reading Test (NART-2nd Edition; Nelson & Willison, 1991); [2]Visual Object Spatial Perception: Incomplete Letters (VOSP-IL; Warrington & James, 1991); [3]Advanced Progressive Matrices (APM, Set 1; Raven, 1965, 1994); [4]Boston Naming Test (BNT-Short Form; Mack et al., 1992); [5]Trails Making Test Part A (Strauss et al., 2006); [6]Spreen & Strauss, 1998; [7]Burgess & Shallice, 1996. 5^{th} percentile cut-offs ($z < -1.645$) for impairment: VOSP-IL (Warrington & James, 1991); NART (Bright et al., 2018); APM (Murphy et al., 2023); BNT (younger – Abeare et al., 2022; older – Fastenbau et al., 1998); TMT (Tombaugh et al., 1998); Stroop (Troyer et al., 2006); HSCT scaled scores (Burgess & Shallice, 1996); HSCT RT and global error score (Burgess & Shallice, 1997); All other cut-offs based on current control sample. Stroop Interference = CW RT / Dot RT. Trails Switching = Trails A RT/ Trails B RT.

different scales). The Semantic Retrieval Response Time Component had low internal consistency (Cronbach's α = .20).

Item analysis

We investigated the internal consistency of Initiation HC and LC reaction times (.63 and .39, respectively), Inhibition reaction times (.82), and Inhibition correct responses (.64). This was consistent with a split-half reliability analysis conducted with healthy controls on the HSCT (Initiation reaction time: .35; Inhibition reaction time: .83; Inhibition Error: .41; Burgess & Shallice, 1996).

Convergent validity

Pearson's correlations were performed to evaluate convergent validity of BELS-SC subtests against the HSCT (see Table 7). Patients and controls were grouped together for these analyses. Reaction times on BELS-SC Initiation and HSCT Initiation subtests were moderately, significantly correlated (N = 134, r = .46, p < .001), indicating convergent validity. This relationship was slightly stronger for high constraint sentences than for low constraint sentences. BELS-SC Initiation HC and LC reaction times and correct responses did not significantly correlate with HSCT Inhibition errors, which demonstrated divergent validity. However, correct responses on the BELS-SC Initiation subtests did not significantly correlate with HSCT Initiation reaction times, possibly suggesting errors and reaction times on sentence completion tasks may tap different aspects of initiation.

Correct responses on BELS-SC Inhibition and HSCT Inhibition subtests were strongly, significantly correlated (N = 148, r = .69, p < .001), indicating convergent validity. Unexpectedly, there was a weak, negative, significant relationship between BELS-SC Inhibition and HSCT Initiation reaction times, such that faster response times were associated with better inhibition. Of note, correct responses on BELS-SC Inhibition were not significantly related to Stroop Interference scores (Color Word reaction time / Dot reaction time; N = 138, r = −0.08, p = .356), which is consistent with Aron and colleagues (2004, 2014) and Cipolotti and colleagues (2016).

Sensitivity and specificity

A ROC curve analysis determined that a score of 18.4/22 on the BELS-SC had an Area Under the Curve (AUC) of .85 (p < .001), sensitivity of .84, and specificity of .66 when distinguishing controls and stroke patients. A series of ROC curve analyses were performed to determine the sensitivity and specificity of the BELS-SC when distinguishing participants who were impaired and intact on standard measures of executive functions (HSCT, Stroop, Trail Making Test, and Verbal Fluency "S"), determined by 5^{th} percentile cut-offs (see Table 8). Participants impaired on one or more of these measures were classified as "impaired." A score of 15.90 was highly sensitive (.83) and specific (.80), with a lower false positive rate than when distinguishing stroke patients and controls.

Group differences on the BELS-SC

LHS and RHS groups were relatively equally impaired on BELS-SC Initiation items (HC and LC); however, there were a greater proportion of RHS patients impaired on Inhibition (particularly HC items), strategy, and total scores (see Figure 1 and Table 9). Controls scored significantly higher than both LHS and RHS;

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Table 4. PCA pattern and structure matrix with oblimin rotation for four factor solution of BELS-SC (controls and stroke)

	Pattern coefficients				Structure coefficients				
	Component				Component				
Item	1	2	3	4	1	2	3	4	Communalities
Inhibition HC /5	**.878**	.019	−.059	−.088	**.926**	−.234	−.462	−.370	.869
Inhibition LC /5	**.903**	.061	−.062	.003	**.914**	−.173	−.430	−.276	.841
Strategy /2	**950**	−.067	.080	.060	**.913**	−.251	−.331	−.220	.845
Initiation HC/5	−.023	**−.981**	.032	.096	.169	**−.938**	−.246	−.163	.892
Initiation HC RT	−.089	**.625**	.119	.306	−.382	**.772**	.468	.551	.804
Inhibition LC RT	.013	−.010	**.935**	.044	−.401	.305	**.941**	.362	.741
Inhibition HC RT	−.085	.037	**.897**	−.089	−.453	.325	**.915**	.258	.666
Initiation LC /5	.046	.005	.114	**−.918**	.275	−.228	−.223	**−.891**	.848
Initiation LC RT	.007	.067	.359	**.593**	−.344	.350	.584	**.734**	.888
Eigenvalue	4.16	1.41	.96	.86					
% Variance explained	46.25	15.68	10.67	9.55					
α	.86	–	.86	–					

Note: Bolded coefficients indicate major loadings for each item. KMO = .804, Bartlett's Test of Sphericity: Chi-square = 862.39(36), $p < .001$. Component 1: Inhibition; Component 2: Initiation; Component 3: Inhibition Response Time; Component 4: Selection. Internal consistencies for Initiation and Selection unable to be calculated due to negative average covariance between variables.

Table 5. PCA pattern and structure matrix with oblimin rotation for four factor solution of BELS-SC (stroke)

	Pattern coefficients				Structure coefficients				
	Component				Component				
Item	1	2	3	4	1	2	3	4	Communalities
Initiation LC /5	**.896**	.003	.114	.048	**.874**	.184	−.213	.317	.876
Initiation LC RT	**−.702**	−.053	.291	.007	**−.812**	−.292	.546	−.348	.854
Inhibition LC/5	.004	**.920**	−.048	−.046	.291	**.930**	−.331	.213	.824
Strategy/2	−.072	**.918**	.097	.097	.211	**.923**	−.295	.197	.900
Inhibition HC/5	.086	**.907**	−.064	−.061	.135	**.898**	−.174	.264	.774
Inhibition LC RT	−.104	.055	**.920**	−.012	−.414	−.234	**.945**	−.353	.752
Inhibition HC RT	.101	−.076	**.913**	−.058	−.251	−.328	**.920**	−.357	.741
Initiation HC/5	−.084	−.017	−.026	**.970**	.254	.209	−.327	**.945**	.860
Initiation HC RT	−.330	−.073	.065	**−.639**	−.588	−.322	.420	**−.793**	.904
Eigenvalue	3.91	1.75	1.00	.82					
% Variance explained	43.47	19.44	11.11	9.15					
α	–	.87	.86	–					

Note: Bolded coefficients indicate major loadings for each item. KMO = .758, Bartlett's Test of Sphericity: Chi-square = 383.644(36), $p < .001$. Component 1: Selection; Component 2: Inhibition; Component 3: Inhibition Response Time; Component 4: Initiation. Internal consistencies for Initiation and Selection unable to be calculated due to negative average covariance between variables.

however, patient groups did not differ (see Table 10 for all BELS-SC group comparison statistics).

Initiation

RHS were significantly slower than controls to initiate a response on Initiation HC items (see Figure 2), and all groups performed at ceiling on raw scores, with only 3 RHS patients performing in the impaired range ($<5^{th}$ percentile). For the age and education-matched comparison, RHS performed significantly worse than controls (accuracy and reaction time; see Supplementary Table 3). **Selection**. LC reaction times were slower for LHS than RHS; however, this difference was non-significant. Controls were significantly faster than patient groups. Both patient groups made significantly more errors on LC items, but did not significantly differ from one another. **Inhibition.** Controls performed significantly better than patient groups, and LHS performed significantly better than RHS on HC but not LC items (see Figure 3). **Error Types**. RHS made significantly more blatant errors than LHS, but patient groups did not differ for partially connected errors (see Figure 4). Controls made significantly fewer blatant errors than RHS but not LHS, and fewer partially connected errors than both patient groups. For the age- and education-matched comparison, only RHS made more partially connected errors than controls (see Supplementary Table 3). **Strategy.** There was a non-significant trend for LHS to show more *instances* of strategy use than RHS ($p = .074$). Controls used significantly more strategies than patient groups; however, groups did not differ for proportion of correct responses that employed a strategy. LHS implemented significantly more semantic strategies (e.g., responding with colors, animals, and foods) than RHS; however, patient groups were equivalent in use of visual strategies (e.g., naming things around the room). Controls used significantly more visual strategies than both patient groups, and more semantic strategies than RHS; however, controls and LHS did not differ in implementation of semantic strategies (see Figure 5). Finally, controls employed significantly more responses that were both visually and semantically related than patient groups, who were comparable.

Discussion

Executive dysfunction is common after stroke and can predict long-term outcomes (Lesniak et al., 2008; Nys et al., 2005, 2007;

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Table 6. PCA pattern and structure matrix with oblimin rotation for four factor solution of BELS-SC (controls)

	Pattern coefficients					Structure coefficients					
	Component					Component					
Item	1	2	3	4	5	1	2	3	4	5	Communalities
Inhibition LC RT	**−.952**	−.056	.037	.042	.098	**−.907**	−.014	.075	−.104	−.259	.681
Inhibition HC RT	**−.837**	.174	−.018	.071	−.109	**−.873**	.211	−.009	−.058	−.415	.625
Initiation LC RT	−.077	**.891**	.163	−.031	.078	−.093	**.883**	.111	.029	.079	.818
Initiation HC/5	−.014	.168	**.907**	−.030	−.106	−.094	.103	**.892**	−.044	−.068	.836
Initiation HC RT	.025	**.587**	**−.605**	.007	−.107	−.019	**.623**	**−.649**	.055	−.107	.935
Initiation LC/5	−.120	−.050	−.041	**.980**	−.080	.008	.028	−.053	**.951**	−.041	.770
Strategy/2	−.129	−.016	−.048	−.153	**.945**	.207	.008	.003	−.089	.880	.817
Inhibition LC/5	.245	.061	−.065	.145	**.626**	.504	.084	−.051	.246	.730	.808
Inhibition HC/5	.342	.142	.151	.351	**.455**	.560	.158	.146	.454	.627	.838
Eigenvalue	2.63	1.40	1.19	1.07	.838						
% Variance explained	29.23	15.53	13.23	11.89	9.31						
α	.74	.20	–	–	.65						

Note: Bolded coefficients indicate major loadings for each item. KMO = .653, Bartlett's Test of Sphericity: Chi-square = 184.799(36), $p < .001$. Component 1: Inhibition Response Time; Component 2: Semantic Retrieval Response Time; Component 3: Initiation; Component 4: Selection; Component 5: Inhibition. Internal consistencies for Initiation unable to be calculated due to negative average covariance between variables.

Table 7. Correlations between BELS-SC and HSCT variables

	Neuropsychology test					
	HSCT initiation RT		HSCT inhibition /15		Stroop interference	
BELS-SC	*r*	τ	*r*	τ	*r*	τ
Initiation HCRT	**.49*****	–	−.05	–	.06	–
Initiation LCRT	**.39*****	–	−.14	–	.10	–
Initiation HC/5	–	.03	–	.01	–	−.00
Initiation LC/5	–	−.15	–	.05	–	.10
Inhibition HC/5	**-.27*****	–	**.66*****	–	−.12	–
Inhibition LC/5	**−.27*****	–	**.64*****	–	−.04	–
Strategy/2	–	**−.17***	–	**.46*****	–	−.03

Note: *$p < .05$, **$p < .01$, ***$p < .001$. *r* = Pearson's r coefficient. τ = *Kendall's Tau coefficient.*

Table 8. Sensitivlty and specificity of BELS-SC in distinguishing executive function "Impaired" and "Intact" participants

Neuropsychology test for EF impairment	AUC	*p*	95% *CI* [LL, UL]	Cut-off	Sensitivity	Specificity
[1]HSCT	.89	.000	.82, .96	15.50	1.00	.71
[2]Stroop CW RT	.78	.000	.66, .91	14.90	.82	.69
Stroop Interference	.69	.044	.51, .87	10.90	.75	.66
[3]Verbal Fluency – S	.82	.000	.74, .90	15.90	.89	.71
[4]Trails B RT	.78	.000	.69, .88	15.50	.80	.67
Any of the above:	.85	.000	.79, .91	15.90	.83	.80
				17.40	.87	.70

Note: RT = "reaction times" in seconds. [1]Burgess & Shallice, 1996; [2]Spreen & Strauss, 1998; [3]Benton et al., 1994; [4]Trail Making Test Part A (Strauss et al., 2006); 5[th] percentile cut-offs ($z < 1.645$) for impairment: HSCT scaled scores (Burgess & Shallice, 1996); Stroop (Troyer et al., 2006); Verbal Fluency – S (Tombaugh et al., 1998); Trail Making Test (Tombaugh et al., 1998); Stroop Interference = CW RT / Dot RT.

Pohjasvaara et al., 2002; Veldsman et al., 2020; Wolf, 2011). Therefore, early assessment of executive functions is crucial for rehabilitation, yet this must be brief due to fatigue and time constraints on an acute stroke ward. The current study introduced the BELS-SC; a standalone, brief (<5 minute) executive screen from the BELS (Robinson et al., 2021; Phillips et al., 2024). The BELS-SC is based on the HSCT (Burgess & Shallice, 1996), but it is different in three key ways: 1) high and low constraint sentence items are included to increase selection demands, 2) Initiation items are repeated to increase Inhibition demands, and 3) a strategy score is incorporated for Inhibition. This study aimed to 1) determine construct validity of the BELS-SC, 2) determine sensitivity and specificity of the BELS-SC, 3) determine convergent and divergent validity of the BELS-SC, and 4) examine the performance of left and right hemisphere stroke on both the BELS-SC and other current standard executive function tests.

Construct, convergent, and divergent validity

Analysis of the BELS-SC among the whole group and stroke group, demonstrated four components: Inhibition (Inhibition HC and LC, Strategy score), Initiation (Initiation HC and Initiation HC reaction time), Inhibition Response Time (Inhibition HC reaction time and Inhibition LC reaction time) and Selection (Initiation LC and Initiation LC reaction time). This was further supported by

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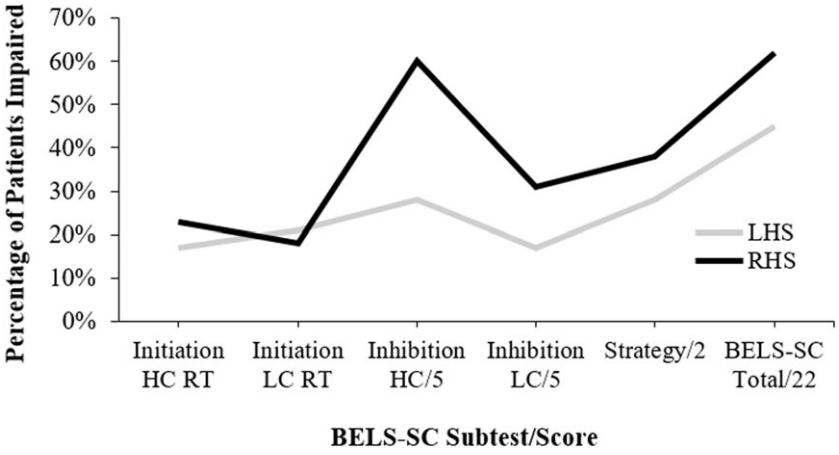

Figure 1. Proportion of LHS and RHS groups impaired (i.e., below 5th percentile) on BELS-SC subtests. LHS = left hemisphere stroke, RHS = right hemisphere stroke, This figure is a visual representation of the "% patients <5th (*n* LHS: *n* RHS: *n* bilateral)" column from Table 3.

Table 9. BELS-SC and standard executive function measures: percent of patients impaired

	% of Patients Impaired	% of LHS Impaired	% of RHS Impaired
BELS sentence completion			
Initiation			
High constraint RT (low selection)	22	17	**23**
Selection			
Low constraint RT (high selection)	19	**21**	18
Inhibition			
High constraint /5	49	28	**60**
Low constraint /5	27	17	**31**
Blatant (A) errors	38	17	**49**
Partial (B) errors	15	10	**16**
Strategy			
Strategy score/2	36	28	**38**
Total BELS-SC (sentence completion)	57	45	**62**
Standard measures of executive functioning			
Victoria stroop interference	5	**12**	2
Victoria stroop CW error %ile	18	**21**	17
Trails Switching	14	**24**	8
HSCT Initiation RT SS	3	**4**	2
HSCT Inhibition RT SS	16	**17**	16
HSCT Inhibition Errors SS	34	25	**40**

Note: "RT" = reaction time, Bolded percentages indicate group with highest proportion of impairment. Impairment on the above standard neuropsychology tests was classified as: Stroop Interference (Color-Word RT/Dot RT) $z < -1.64$ and error percentile ("%ile") < 5th (as per Troyer et al., 2006); Trails Switching (Trails B RT/Trails A RT) <5th percentile of the current healthy control sample; HSCT scaled scores <3 (as per Burgess & Shallice, 1997).

good internal consistency of Inhibition HC and LC items (for both errors and reaction times), and poor consistency between Initiation HC and LC items (i.e., HC and LC reflect different constructs). Individual BELS-SC Initiation and Inhibition items showed similar internal consistency to that of the HSCT (Burgess & Shallice, 1996).

Although it was expected that strategy would be a standalone component on the BELS-SC, it is unsurprising that strategy loaded on inhibition. This is because strategy is a process used to assist with suppression of prepotent responses. Maintaining the inclusion of a strategy score as part of the BELS-SC has important implications for understanding a patient's ability to generate and implement a strategy, which is very relevant for problem-solving and achieving rehabilitation goals. Unexpectedly, Inhibition reaction times and errors did not load on the same factor. Beyond suppression of the prepotent response (Inhibition component), the Inhibition Response Time component may reflect additional processes related to Inhibition (e.g., time to think of a work, task switching, monitoring, adjusting, generating a strategy: Aron et al., 2014; Chatham et al., 2012).

When only controls were included in the PCA, the BELS-SC demonstrated five components: Inhibition Response Time (Inhibition HC reaction time and Inhibition LC reaction time), Semantic Retrieval Response Time (Initiation HC reaction time and Initiation LC reaction time), Initiation (Initiation HC total correct and reaction time), Selection (Initiation LC total correct), and Inhibition (Inhibition HC and LC total correct, and Strategy score). The two key differences from the PCA with the whole sample and stroke only group were 1) an additional component reflecting the time taken to retrieve and initiate the appropriate semantic word, of both high and low constraint conditions, and 2) Initiation LC reaction time did not load with Initiation LC correct on the Selection component. It is possible that Initiation HC and LC reaction times loaded together for controls due to less disparity between time taken to retrieve a word in high and low constraint conditions, than there is for stroke. It is likely that stroke patients are slower to select from multiple competing responses and still may not be able to produce a one-word answer that meaningfully completes the sentence within the 20 s time limit.

In relation to convergent validity, the BELS-SC Initiation and Inhibition subtests demonstrated good convergence with HSCT Initiation and Inhibition, respectively. We note that the BELS-SC HC Initiation items were more strongly correlated with the HSCT than LC items, which was likely due to the increased selection demands and slower response times on LC items. Divergent validity was also established, with no significant relationship between BELS-SC Initiation variables and HSCT Inhibition. Unexpectedly, there was a weak but significant relationship between BELS-SC Inhibition and HSCT Initiation reaction time, suggesting participants who were faster to initiate a semantically connected response were better at suppressing prepotent responses on the BELS-SC Inhibition subtest.

Sensitivity and specificity

As predicted, the BELS-SC demonstrated good sensitivity but poorer specificity when distinguishing stroke patients from healthy controls. It is likely that poorer specificity is due to the older age of the control group because age-related declines in executive

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Table 10. BELS-SC comparisons for controls, LHS, and RHS

	Kruskal-Wallis				*Pairwise Comparisons*				
	N	*H*	*df*	*p*	*Groups*	*N*	*U*	*p*	*r*
BELS-SC									
Initiation									
High Constraint /5	202	6.82	2	.033	-	–	–	–	–
High Constraint RT	195	13.67	2	**.001**	R - L	86	761.00	.211	–
					C < R	166	2103.50	**< .001**	.26
					C - L	138	1149.00	.024	–
Selection									
Low Constraint /5	202	10.92	2	**.004**	R - L	86	871.50	.641	–
					C < R	173	2646.00	**.007**	.21
					C < L	145	1259.00	**.007**	.22
Low Constraint RT	195	27.76	2	**< .001**	R - L	86	674.00	.164	–
					C < R	166	1999.00	**< .001**	.29
					C < L	138	706.00	**< .001**	.39
Initiation (Weighted) /10	195	20.83	2	**< .001**	R - L	86	866.50	.708	–
					C > R	166	2106.50	**< .001**	.29
					C > L	138	920.50	**< .001**	.32
Inhibition									
High Constraint /5	199	71.49	2	**< .001**	**R < L**	84	463.50	**.001**	.35
					C > R	170	797.00	**< .001**	.62
					C > L	144	914.50	**< .001**	.33
Low constraint /5	199	55.83	2	**< .001**	R - L	84	578.50	.035	–
					C > R	170	993.50	**< .001**	.57
					C > L	144	1037.00	**.001**	.27
Errors									
A: Connected errors	196	51.72	2	**< .001**	**R > L**	83	1103.50	**.003**	.32
					C < R	167	5000.00	**< .001**	.56
					C < L	141	1958.00	.037	–
B (Partially connected) errors	196	30.75	2	**< .001**	R - L	83	973.00	.095	–
					C < R	167	4647.50	**< .001**	.42
					C < L	141	2107.50	**.012**	.21
Strategy									
BELS strategy /2	199	59.20	2	**< .001**	R - L	84	615.50	.069	–
					C > R	170	1228.50	**< .001**	.59
					C > L	144	1072.50	**< .001**	.34
C5: Visual	199	49.67	2	**< .001**	R - L	84	686.00	.242	–
					C > R	170	1146.00	**< .001**	.52
					C > L	144	975.50	**< .001**	.29
C6: Semantic	199	13.09	2	**.001**	**R < L**	84	551.00	**.008**	.29
					C > R	170	2200.50	**< .001**	.27
					C - L	144	1728.50	.748	–
C7: Visual and semantic	199	18.32	2	**< .001**	R - L	84	827.50	.579	–
					C > R	170	2353.00	**< .001**	.26
					C > L	144	1194.00	**.003**	.25
Proportion correct *w* strategy	186	7.57	2	.023	–	–	–	–	–
Sentence Completion /22	192	69.87	2	**< .001**	R - L	84	628.50	.111	–
					C > R	163	754.50	**< .001**	.61
					C > L	137	636.50	**< .001**	.42

Note: Bonferroni correction applied to Kruskal–Wallis analyses (HSCT: $\alpha = .007$, BELS-SC: $\alpha = .003$) and follow-up pairwise comparisons ($\alpha = .017$). *C* = Controls, *R* = RHS, *L* = LHS.

functioning has been well documented (e.g., Gibson et al., 2018; Madden et al., 2019; Martin et al., 2021). However, in the current context of acute/early stroke, it is more important for a screen to be sensitive (i.e., detect impairment) rather than specific (i.e., low false positive rate), as this enables potential rehabilitation targets to be identified in a timely manner. Due to the BELS-SC not being a tool to diagnose stroke, sensitivity and specificity were also investigated to determine if the BELS-SC could differentiate between participants who were intact versus impaired on standard, widely used executive function measures. A score of 15.9/22 on the BELS-SC showed similar good sensitivity, and better specificity than when distinguishing controls and stroke patients. The latter is unsurprising given the likely age-related decline in executive functioning for some healthy participants. In addition to use in a stroke population, the BELS-SC may be a valuable early-detection measure for executive impairment in healthy aging.

Left and right hemisphere stroke and the BELS-SC

As expected, LHS and RHS showed different patterns of impairment across the BELS-SC components. However, unexpectedly, on the BELS-SC Initiation items the RHS group were significantly slower than controls to initiate a response regardless of level of constraint, whereas LHS were significantly slower than controls only on low constraint (high selection demand) items. Further, compared to the age and education-matched control group, RHS made significantly more errors on high constraint (low selection demand) items. Slowed energization has been linked to right medial frontal regions, which may partially explain the RHS group showing slower response latencies than controls across both high and low selection items (Stuss & Alexander, 2007). While there was a similar proportion of LHS and RHS impaired on BELS-SC Initiation HC reaction times, LHS and controls did not significantly differ at the group level. It is possible more profound

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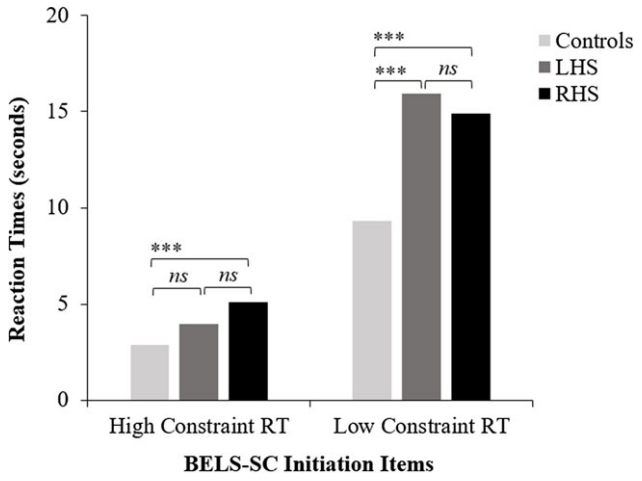

Figure 2. BELS-SC initiation reaction times for controls, LHS, and RHS. LHS = left hemisphere stroke, RHS = right hemisphere stroke, ***$p < .001$. "ns" = non-significant p value. This figure plots group means for BELS-SC initiation HC and LC reaction times and displays results from Kruskal–Wallis and follow-up pairwise Mann–Whitney U tests.

selection deficits in LHS were not observed due to the wide range of lesions within the left hemisphere, rather than being localized to the LIFG, which is an areas linked to selection (Barker et al., 2020; Benedek et al., 2014; Fink et al., 2009; Madden et al., 2019; Moss et al., 2005; Robinson et al., 1998, 2005, 2010; Thompson-Schill et al., 1997; Zhang et al., 2004).

For the BELS-SC Inhibition items, patients were most impaired for HC items, with half of all patients (49%) performing below the 5th percentile. Of note, on LC items, the percentage of impaired patients dropped to 27%, highlighting a greater level of difficulty for the HC items. The latter likely reflects the fact that HC items elicit one dominant word to override and suppress. Although both patient groups were impaired on inhibition, the RHS group was disproportionately affected, particularly on HC items (60% of RHS; 28% of LHS) and were significantly poorer than LHS on these items. RHS patients also made more blatant inhibition errors than both controls and LHS, whereas both RHS and LHS made significantly more partially connected inhibition errors than controls (NB: only RHS made more partially connected errors in age and education-matched comparisons). This aligns with prior studies linking inhibition processes to right frontal regions (Aron et al., 2004, 2014; Cipolotti et al, 2016a, 2016b; Kawashima et al., 1996; Konishi et al., 1998; Robinson et al., 2015b; Volle et al., 2012; Wilson et al., 1998). However, the level of impairment in the LHS group was not negligible, which suggests some bilateral involvement in inhibition.

Patient groups employed significantly fewer strategies than controls, particularly visual (C5) and both visual and semantic strategies (C7). Notably, semantic strategy use (C6) did not differ between controls and LHS; however, RHS used significantly fewer semantic strategies than both groups. This may be due to semantic strategies being slightly more difficult to generate than a visual strategy. Further investigations into strategy use in stroke may help inform cognitive rehabilitation practices (e.g., implementing visual strategies rather than semantic strategies to overcome inhibition impairments). Additionally, strategy generation and implementation have been shown to be distinct processes, with brain tumor patients showing differential capacity to generate and implement a strategy (Robinson et al., 2015a, 2016). This is a potentially beneficial avenue to further explore in stroke rehabilitation. Interestingly, the proportion of correct responses that employed a strategy did not differ between controls and patients, which suggests correct responses were facilitated by strategies, rather than by responding with random words without an obvious strategy.

Executive function tests and the BELS-SC

Despite some similarities between the BELS-SC and HSCT, as anticipated there were differences in how patients performed on these measures. Although the number of patients impaired on BELS-SC and HSCT (raw scores) were comparable, more patients were impaired on the BELS-SC composite score (57%) compared to HSCT overall scaled score (21%). This is likely due to the three key differences in that the BELS-SC comprises i) high and low constraint sentences, ii) repetition of initiation items for inhibition, and iii) the inclusion of a strategy score. A primary strength of the BELS-SC is the novel inclusion of high and low constraint Initiation sentences, which are repeated for Inhibition. While the number of patients impaired on LC Inhibition items (27%) are comparable to those impaired on HSCT Inhibition (28%), 49% of patients were impaired on BELS-SC HC items. This suggests the BELS-SC can detect more inhibition impairments than the HSCT due to increased demands placed on inhibitory processes. This would align with the notion true inhibition requires an automatic, dominant response to be produced, before it can then be suppressed (Aron et al., 2014; Friedman & Miyake, 2004; Li et al., 2021; Miyake et al., 2000).

It was found that LHS were disproportionately impaired on standard executive function measures such as Stroop Interference and Trails Switching, whereas RHS were disproportionately impaired on the BELS-SC (particularly inhibition). In line with previous research, the Stroop test (commonly viewed as a test of inhibition) was not related to BELS-SC Inhibition. Further, patients did not differ from controls on Stroop interference scores or Color Word percentiles; however, they differed significantly on HSCT Inhibition (raw and scaled scores) and BELS-SC Inhibition. These results add to growing literature suggesting that the Stroop and sentence completion tests tap dissociable functions (Aron et al., 2014; Cipolotti et al., 2016b; Moore et al., 2024). As previously noted, a limitation of the Stroop test is that it may not tap true inhibition (Aron et al., 2004, 2014; Stuss & Alexander, 2007). This is evident behaviorally when comparing performance on the Stroop to the HSCT and BELS-SC, but also anatomically in lesion symptom and advanced network-level lesion mapping studies (Cipolotti et al., 2016b; Moore et al., 2024). It is also important to note that use of a visual strategy on the Stroop or using a visual or semantic strategy on the HSCT may mean true inhibition is not required (e.g., focusing on the last letter of the word to be inhibited for Stroop, or ignoring the sentence while implementing a semantic strategy on the HSCT). Although this might also apply to the BELS-SC, the repetition of Initiation items for Inhibition means the sentence has already been processed meaningfully and each individual has already produced a prepotent response for each item, which increases the likelihood that it must then be suppressed.

Implications

A major implication is related to the notion that executive functions are comprised of a collection of abilities rather than one common function (Martin et al., 2021; Miyake et al., 2000; Stuss &

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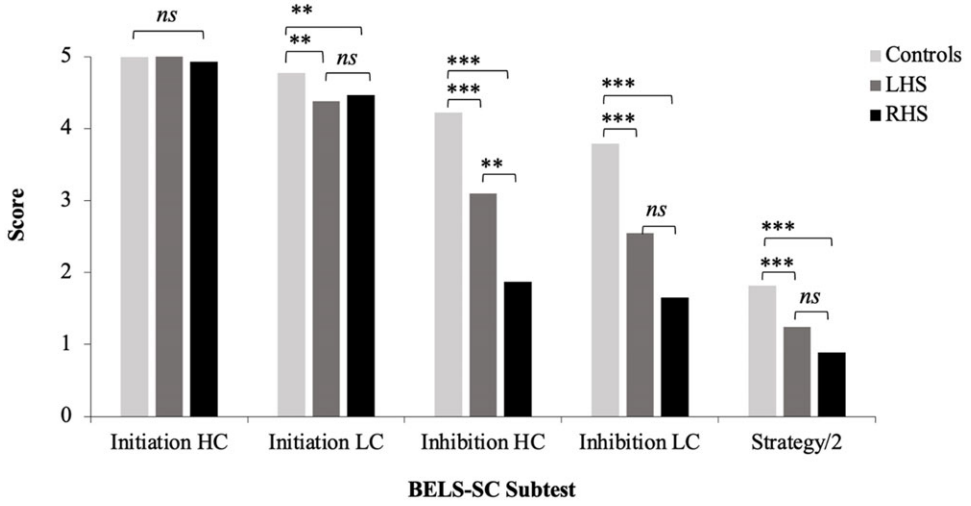

Figure 3. BELS-SC subtest scores for controls, LHS, and RHS. LHS = left hemisphere stroke, RHS = right hemisphere stroke, $^{**}p < .01$, $^{***}p < .001$. "ns" = non-significant *p* value. This figure plots group means for BELS-SC initiation and inhibition raw scores and displays results from Kruskal–Wallis and follow-up pairwise Mann–Whitney *U* tests.

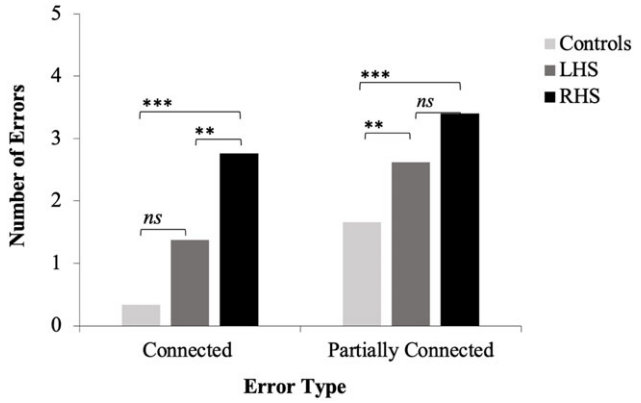

Figure 4. BELS-SC error type for controls, LHS, and RHS. LHS = left hemisphere stroke. RHS = right hemisphere stroke. $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$. "ns" = non-significant *p* value. This figure plots group means for BELS-SC inhibition error types and displays results from Kruskal–Wallis and follow-up pairwise Mann–Whitney *U* tests.

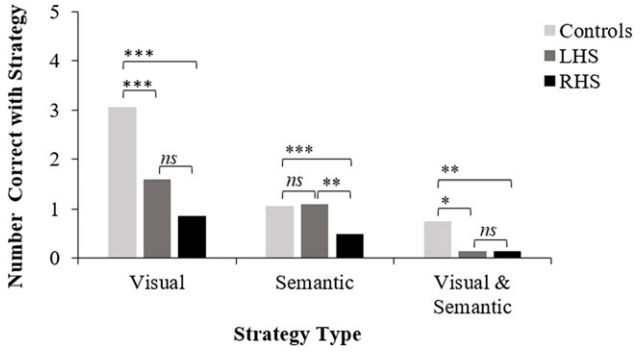

Figure 5. BELS-SC strategy use for controls, LHS, and RHS. $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$. "ns" = non-significant *p* value. This figure plots group means for BELS-SC inhibition strategy types and displays results from Kruskal–Wallis and follow-up pairwise Mann–Whitney *U* tests.

Alexander, 2007). One executive function measure cannot capture all executive processes, and therefore many executive impairments likely go undetected using current cognitive screens in stroke. Advantages of the BELS-SC are that it taps multiple executive functions (initiation, selection, inhibition, inhibition response time, and semantic retrieval response time), it provides insight into strategy use within 5 minutes, and it can be completed at bedside. Thus, the BELS-SC can provide valuable guidance for cognitive rehabilitation. For example, patients with an initiation impairment have benefitted from cueing, whereas patients with a selection deficit would require options to be limited to one or two possibilities, with minimal open-ended questions (Robinson et al., 2016). Inhibition deficits may benefit from implementing a process to increase awareness to override or stop, which can be enhanced via strategies, and may also be improved by targeting adaptive behaviors that require the control mechanisms of initiation, selection, and inhibition (Robinson et al., 2015b, 2016).

Additionally, executive functioning in acute stroke can predict long-term stroke outcomes (Lesniak et al., 2008; Nys et al., 2005, 2007; Pohjasvaara et al., 2002; Veldsman et al., 2020; Wolf, 2011). Therefore, investigating the utility of the BELS-SC as a prognostic tool would possibly assist in identifying patients most at risk for poorer long-term stroke outcomes, including cognition, daily functioning, mental health, and quality of life.

Limitations

Due to the range of stroke lesions, the relationship between BELS-SC performance and specific brain regions (e.g., selection in LIFG patients) could not be determined. Post hoc analyses investigating subgroups with specific strokes (e.g., left middle cerebral artery, anterior cerebral artery), could not be performed due to small numbers. Future network-level lesion mapping (as in Moore et al., 2024) to explore BELS-SC performance would enhance our understanding of regions and networks implicated in each executive process tapped by this task. Further, ceiling effects on the Initiation HC items (number correct) meant individual BELS-SC items were unable to be entered into the PCA, and instead subtotals were used. However, we note that if these items were not at ceiling, it would raise questions as to whether any selection and inhibition impairments were in fact due to underlying initiation and/or semantic retrieval impairments. Further investigation into construct validity and internal consistency in other neurological populations may be beneficial in understanding the executive components captured by the BELS-SC.

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Conclusion

In summary, the BELS-SC was found to demonstrate good construct, convergent, and divergent validity, and had good sensitivity but poorer specificity when distinguishing healthy controls and stroke patients. When classifying executively impaired versus intact participants, both sensitivity and specificity were good. The BELS-SC is a useful bedside screening tool that can detect executive dysfunction in acute to early sub-acute left and right hemisphere stroke patients. This is critical when patients do not present with severe and/or obvious cognitive impairments, which may then go undetected on current cognitive screens. In an early stroke setting, the BELS-SC can inform targets for rehabilitation, or it can be a brief triage initial cognitive screen for comprehensive neuropsychological assessment.

Supplementary material. The Supplementary Material for this article can be found at https://doi.org/10.1017/S1355617725101112.

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Competing interests. The authors declare no conflicts of interest.

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