Systematic Review

Neurocognitive Function Following Out-of-Hospital Cardiac Arrest: A systematic review

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**Abstract:**

*Objectives:* The primary aim of this review was to investigate neurocognitive outcomes following out-of-hospital cardiac arrest (OHCA). Specifically, the focus was on identifying the different neurocognitive domains that are assessed, the measures used, and the level of, and criteria for, impairment.
*Design and review methods*: A systematic review of the literature from 2006 to 2021 was completed using Medline, Cinahl and Psychinfo. Criteria for inclusion were studies with participants over the age of 18, OHCA and at least one neurocognitive function measure. Qualitative and case studies were excluded. Reviewers assessed criteria and risk of bias using a modified version of Downs and Black.
*Results:* Forty-three studies were identified. Most studies had a low risk of bias (n=31) or moderate risk of bias (n=11) and one had a high risk; however, only six reported effect sizes or power analyses. Multiple measures of neurocognitive outcomes were used (>50) and level of impairment criteria varied considerably. Memory impairments were frequently found and were also more likely to be impaired followed by executive function and processing speed.
*Discussion:* This review highlights the heterogeneity of measures and approaches used to assess neurocognitive outcomes following OHCA as well as the need to improve risk of bias concerning generalizability. Improved understanding of the approaches used for assessment and the subsequent findings will facilitate a standardized evaluation of neurocognitive outcomes following OHCA.
**Keywords:** out-of-hospital cardiac arrest, neurocognitive outcomes, memory, executive functions

1. Introduction

Outcomes from out of hospital cardiac arrest (OHCA) are poor with high mortality; survival rates at hospital discharge are on average 8%, varying from 0% to 18%1. For those who survive, neurocognitive impairment is often a concern; however, understanding of the type and level of impairment is limited. A systematic review by Moulaert et al2 found that the frequency of impairments reported after OHCA varied considerably, from 6% to 100%. The authors note the paucity of high-quality studies assessing neurocognitive outcomes. Specific weaknesses included: concerns with the patient populations used, the small sample size, the heterogeneity of assessments, and the lack of consideration of factors such as age, sex, and treatment. A more recent review over a seven-year period also notes the difficulty of generalizing findings across cardiac arrest studies3.

Deficits in neuropsychological domains (e.g., attention, memory, executive function) are likely associated with damage to areas that are particularly vulnerable to the effects of hypoxia, associated with out-of-hospital cardiac arrest. This is supported by studies showing specific decreases in the volume of areas of the brain such as the hippocampus, the anterior cingulate cortex, the dorsolateral prefrontal cortex, and the striatum 4,5. These areas are associated with core deficits identified following OHCA in the neuropsychological domains of memory, attention and executive functions. Deficits in these areas for patients classified as having a ‘good outcome’ may be overlooked or underestimated, particularly when measures are used that are not sensitive to minor or subtle changes in neurocognitive function are used, creating a “ceiling effect” 6. The patient may therefore be discharged without appropriate rehabilitation, or inadequately prepared to deal with the challenges that will follow in carrying out daily activities.

This systematic review of recent studies extends findings from the previous review by considering recent studies specifically focused on OHCA. The primary aims of this review were to identify: (1) the areas of neurocognitive function assessed following OHCA; (2) the specific measures used; (3) the timing of the assessment; (4) the prevalence and degree of impairment identified, and the criteria used to identify impairment. Studies were also reviewed for risk of bias in order to determine the strength of the evidence.

2. Methods

*2.1 Search Strategy*

Using Medline, Cinahl and PsycInfo a systematic literature review was completed (Prospero CRD42019149075). This included articles from January 2006 to August 2021. Additional searches were conducted over this time period using reference lists from papers selected and Google scholar (NZ). No additional papers were identified through these searches. The search terms included both cardiac arrest population terms and neurocognitive outcomes (**Appendix 1**). Articles were selected if they included at least one neurocognitive assessment in OHCA survivors over the age of 18 years and were either written in English or there was a translation available. Studies including both in- and out-of-hospital cardiac arrest were excluded if it was not possible to identify neurocognitive outcomes specific to the OHCA group. Functional outcome measures typically used at discharge -i.e., Cerebral Performance Category (CPC)7, Glasgow Outcome Scale8 (GOS) and modified Rankin Scale (mRS)9 – were alsoexcluded as the focus here was on measures of neurocognitive performance beyond discharge. Case studies and qualitative studies were also excluded.

Initially, articles were reviewed for inclusion and exclusion criteria using titles and abstracts (NZ). Following this, full texts were reviewed independently by two researchers (NZ, SV). Where consensus was not reached, input was sought from other reviewers (JB, SJB, EJ).

*2.2 Quality appraisal*

Quality was independently assessed using a modified version of a Downs and Black checklist for nonintervention studies10,11 by two reviewers (NZ, EBN). A third reviewer (SV) assessed articles by EBN and co-authors. Quality was assessed using fifteen items scored as either 0 (absent or unable to determine) or 1 in the following categories: reporting (0-7), external validity (0-3), internal validity (0-4) and statistical power (0-1). Overall scores were used to identify the quality of the study in relation to the risk of bias. Those scoring 0-6 (40%) were considered low quality/high risk of bias, those scoring 7-9 (40-60%) being medium quality and over 10 as high quality/low risk for bias (60%). This quality appraisal was based specifically on the reporting of neurocognitive assessments rather than the overall focus of the study (e.g., other outcomes). Therefore, some studies with low ratings for the purposes of this review may be considered high quality when rated on other criteria for the study overall. Where quality appraisal differed, a third reviewer arbitrated (SV).

*2.3 Data extraction*

Data extracted from articles included the following: authors and date; study type; criteria for inclusion/exclusion; participant numbers and characteristics (age, sex, ethnicity, therapeutic hypothermia); functional outcome measures; follow-up times; objective and subjective neurocognitive outcome measures; other measures used; how impairment was defined; the type and degree of impairment found.

3. Results

The initial search yielded 5393 records which were imported for screening. Prior to review, 177 duplicates were removed leaving 5216 studies for title and abstract screening. From these, 517 studies were assessed for full-text eligibility; 474 studies were excluded leaving 44 studies for inclusion. Two articles12,13 contained overlapping results and only one was included in the full review to give a total of 43 studies (see **Figure 1** for Prisma flowchart and **Table 1** for the included studies). The study designs varied and included prospective studies (32) and retrospective studies (11).

3.1 Quality Assessment

Quality assessment scores from the Modified Downs and Black were found to have quality (risk of bias) percentage ranges from 33% to 93% with higher scores indicating lower risk of bias. Papers were then rated as having either a high (<40%), moderate (40-60%) or low level (>60%) of risk of bias (see **Table 1**). There were twenty-eight studies rated as low risk of bias, ten as moderate, and one as high. Cohen’s K was run to identify agreement between the rater’s judgment; K= 0.89, p <0 .01. The mean score across the 15-items was 10.08 (SD=2.84). For the reporting subscale (7 questions), the mean was 5.45 (SD=1.77); for external validity subscale (3 questions) the mean was 1.52 (SD=0.90); for internal validity (4 questions) the mean was 2.95 (SD= 1.06). Only six studies reported a power calculation14-19. Proportions on the external validity scores (.51) were lower than those on the reporting (.77) and internal validity (.73) subscales.

3.2 Study population

The mean age of participants ranged from 50 (SD=15)20 to 7221. The number of OHCA participants varied from 821 to 287 22. All the articles reviewed reported a higher percentage of males than females, ranging from 6614, 16,23 to 100%.21 Ethnicity was not reported in most studies. Most (n=29) studies reported that participants, or a subset of participants, had received some form of therapeutic hypothermia. The inclusion and exclusion criteria for OHCA patients varied between studies, with some restricting inclusion to a CPC of 1 or 2 (good outcome); however, others either did not specify criteria and likely included survivors with more severe outcomes.

3.3 Outcome measures and follow-up

Follow-up time for the neurocognitive measures varied from hospital discharge24 to eighteen years21. Fifty-four different measures were used to assess neurocognitive function. The types of measures ranged both in relation to the method of administration (interview, self-report questionnaire, informant questionnaire, neuropsychological test) and the domain of function being measured (see **Table 1)**. The criteria used to identify impairment varied across studies making direct comparisons, even when using similar measures, difficult. Given the heterogeneity of studies reviewed, a narrative synthesis approach is used to summarise main findings.

When assessing overall and global cognitive function screening tools, the Mini-Mental Status Exam (MMSE)25, the adapted version for use via telephone (MMSE-Adult Lifestyles and Function Interview, MMSE-ALFI)26, and the Montreal Cognitive Assessment (MoCA)27 were used. Where MMSE was reported, the percentage ranged from no participants showing impairment28 (cut-off of 28) to 50% of participants (cut-off of 26) showing impairment.21 The MoCA impairment rate ranged from 54%29 to 88%21 using the standard cut-off criteria of 26. It should be noted that the higher rates of impairment reported by Andersson et al21 need to be interpreted with caution due to the low sample size (n=8) and long follow-up time (15-18 years) compared with other studies.

When assessing specific domains of neurocognitive impairment, memory (23), executive function (17) and attention/information processing (10) were assessed most frequently. Studies also included measures of general neurocognitive ability, motor function, language, and visuo-perceptual measures. Memory measures varied and included both short- and long-term memory measures as well as working memory and visuospatial memory. Participants showing memory impairment ranged from 10% on the Rey CF30 to 94%31 using a memory composite variable (RAVLT, DSF, and BVRT). The most common memory measures were verbal learning tests (i.e., CVLT, RAVLT) which assess both episodic learning and memory and delayed recall. All of the studies reviewed identified some degree of impairment. Participants showing executive function impairment ranged from 8%32 to 62%31. For attention and information processing, impairment levels ranged from 0%31,20 to 57%33. Most studies used performance-based measures, though others used self-report measures (e.g., CFQ34, DEX19) from survivors or informants (e.g., IQCODE6,29,33,35, IQCODE-CA36,37) or questions relating to recovery (e.g., 2SQs35, Perception of Recovery38). Again, there was a range of impairment reported; from 0% (DEX)19 to 62% (IQCODE)35.

Participant characteristics (age, sex) and treatment varied (therapeutic hypothermia, type of CPR, etc.), as did the time to follow-up (e.g., discharge38 to 18 years21). Multiple studies included measures of depression, anxiety and quality of life.

**Figure 1.** Prisma flowchart of the literature search and selection process.



**Table 1.** Summary of studies and outcome measures, level of impairment and criteria used.

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| **Reference (author & year)** | **Risk of Bias** | **study type** | **N (cog tests)** | **Follow-up (days/months)** | **Cognitive domain assessed (measure)a** | **Impairment and/or differences from other populations** | **Criteria Used** |
| Alexander et al., 201139 | low | Pros | OHCA: 30, Controls:30 | Ps: 113 days (26.5), Cs: 109 (17.5) | Premorbid function (NART) Memory (RAVLT, BVMT-R); EF (Trails B, VF, WCST); Semantic (BNT, PPV); Perceptual (JOL, Number location, Visual Discrimination); Psychomotor (Trails A, GP, Finger tapping) | OHCA composite scores lower than coronary controls on all domains; Memory 37%; Motor 27%; Semantic (21%), EF 13% | Norms; 2 SDs |
| Anderrson et al., 201521 | mod | Retro | 8 | 15-18 years | Global cognitive function (MMSE, MoCA) | MMSE 50%; MoCA 88% | MMSE <27; MoCA < 26 |
| Aufderheide et al., 201114 | mod | Pros  | OHCA: 48 Controls: 74 | 90 days, 365 days | Global cognitive function (CASI) | NR, did not find a sig difference between treatment groups (CPR/Intervention) | Cut-off scores |
| Beesems et al., 20146 | low | Pros | 220 | 6-13 mos, median 9 | Global cognitive function (IQCODE or TICs) | IQCODE/TICS 18% | NR |
| Blennow Nordstrom et al., 201736 | low | Pros | 268 | 180 days +/- 14 | Global cognitive function (MMSE, IQCODE-CA), Memory (RBMT) | 53% | MMSE <27 and RBMT profile score <17; IQCODE CA: >3.04 |
| Bro-Jeppesen et al., 200915  | low | Pros | G1: 28; G2: 26 | 6 mos | Global cognitive function (MMSE) | <1% | MMSE < 24 |
| Brønnick et al., 202140 | low | Retro | \*see Evald et al., 2019 |  | Premorbid function (Vocabulary, WAIS-IV);Memory (RAVLT, Rey CF); Attention (Trails A & B; DS WAIS-IV); EF (D-KEFs verbal fluency) | 22% | Norms; impaired = below cut-off ≥ 3 measures |
| Byron-Alhassan et al., 202041 | low | Pros | OHCA: 9,Controls: 12MI: 19 | OHCA: 13.78 (13.04), MI: 40.52 (21.96) | NAB Global Score | NR, mean scores did not show impairment | Norms |
| Byron-Alhassan et al., 202142 | mod | Pros |  |  | NAB (Attention, Memory, Language, Executive, Spatial) | Overall 42.9%; Attention 55.8%; Memory 45.5%; Language 41.6%; EF 29.9%; Spatial 16.9% | Norms |
| Caro-Codon et al., 201829 | low | Pros | 79 | 3.1 yrs (1.7-4.4) | Global cognitive function (MoCA; Modified IQCODE); Executive function (Trails B)  | MoCA 54.4%; Trails B: 24%; IQCODE 12% | Trails: Population Norms; MoCA <26;  |
| Cronberg et al., 201535 | low | Pros | G1: 213; G2: 206 | ~6 mos (median: 186 days) | Global cognitive function (MMSE; MMSE ALFI, IQCODE, 2 Simple Questions, recovery) | MMSE 31%; IQCODE 62%; 2SQ 33.5% | MMSE <27; IQCODE >78 |
| Davies et al., 201744 | low | Retro | 41 | ~3 months, 4 at mos, 1 at 9 mos | Global cognitive function (MMSE);Visuo-spatial memory (DMS:Cantab) | MMSE M=27.5 (2.37); % under cutoff NR | NR |
| Evald et al, 201916 | low | Retro | 79 | G1: M=187 (181-204 days); G2; 188 (181-198) | Premorbid function (Vocabulary, WAIS-IV); Memory (RAVLT, Rey CF); Attention (Trails A & B; DS WAIS-IV); EF (D-KEFs verbal fluency) | G1: 33%; G2: 12% | Norms; impaired = below cut-off ≥ 3 measures |
| Evald et al., 202144 | low | Pros | 79 | 187 (181-201) | Subjective Cognitive Function: CFQ  | 6.8% | CFQ raw scores |
| Fugate et al, 201323 | low | Pros  | 56 | 19.5 mos (14.3-24 mos) | Global cognitive function (TICs) | 40% | TICs <32 |
| Grand et al., 201937 | low | Retro  | 237 | 6 mos | MMSE; IQCODE-CA | MMSE 35%; IQCODE-CA 28% | MMSE <27; IQCODE >83 |
| Grubb et al., 200738 | low | Pros | 49 | within 24-hrs of discharge, (5-26 days postarrest) | Premorbid function (NART); Memory (RBMT, WMS-R D-S) | RBMT:57% | RBMT Norms >21 |
| Harve et al., 200720 | high | Retro | 10 | ~15 yrs | Memory (Logical memory WMS),Visuo-constructive and visuomotor speed (Block design and Dig-Sym WAIS) | Memory 40%; Visuo-constructive 20% | Norms, 2 SDs |
| Heradstveit et al., 201128 | mod | Pros | 9 | MRIs at 2 h, 24 h and 96 h; M=22 (15-26) mos | MMSE | 0% | MMSE <27 |
| Ji et al., 201713 | mod | Pros | 3 mos: G1:96, G2: 182 at 12 mos G1(mech): 89; G2:175 | 3 mos, 12 mos | MMSE | M=26.9 (3.7) & M=28 (2.3); % under cutoff NR | NR |
| Juan et al., 201845 | low | Pros | 50 (42 complete) | 6 mos | Subjective general function (Perception of recovery); Memory (CVLT, Doors and People, DSF WAIS-IV, block tapping WMS-3rd); Language (Naming subtest Lexis); Productivity (5 points test), Processing Speed (D-Sym WAIS-IV), Attention (Alert and Divided subtest,Test battery for attn performance),EF (verbal fluency, Trails, Stroop, FAB GREFEX) | Subj function: 30%; Neurocognitive tests: 26% overall; Processing speed 21%, Language 21%, LTM 19%, EF 19%, STM verbal 5%, attention 5-29% | Norms, SDs 1.65; Global Cognitive Impairment: # of domains impaired out of 13, >3 substantial cog impairment |
| Lilja, Nilsson, et al., 201533 | low | Pros | G1: 278; control STEMI: 119 | 180 days | Global cognitive function (MMSE, IQCODE, 2SQ); Memory (RBMT); EF (FAB); Processing Speed (SDMT) | NR; Sig correlations between neurocognitive performance and psychological distress (HADS)  | NR |
| Lilja et al., 201822 | low | Pros | G1: 287; G2(control) 119 | 6 mos | Memory (RBMT); EF (FAB); Processing Speed (SDMT)  | 47%; specific details NR | RBMT < 22; FAB < 14; SDMT 1.5 SDs |
| Lilja, Nielsen et al., 201546 | low | Pros | as above | ~6 mos | Memory (RBMT); EF (FAB); Processing Speed (SDMT)  | RBMT 51-58%; FAB 20-23%; SDMT 52-57%  | RBMT < 22; FAB < 14; SDMT 1.5 SDs |
| Lim et al., 201447 | mod | Pros  | G1: 25; G2 (con, ACS): 27 | 3 mos, 12 mos | Premorbid function (ANART); Memory (RAVLT, BVMT-R); EF (Trails B, VF, WCST); Language (BNT, PPV); Visuo-perceptual (JOL, Number location, Visual discrimination); Psychomotor (Trails A, GP, Finger tapping) | T1: see Alexander et al., 2011; T2: Memory 64%; EF 32%; Semantic 24%; V-P 28%; Psychomotor 52% | Norms, Composite z-score |
| Longstreth et al., 201048 | mod | Pros  | 32 | ~3 mos | Global cognitive function (ALFI-MMSE; 2SQs) | 2SQs 25% | Raw scores |
| Mateen et al., 201149 | low | Retro | 47 | 7.8 yrs (median) | Global cognitive function (MMSE), General cognitive ability (WASI -MR, block design), Memory (RAVLT), Language (COWAT), EF (Stroop, Trails A & B) | MMSE 4%; WASI: 4%; AVLT: 24-38%; Trails 17%, Stroop 11% | Norms; 1 SD |
| Moulaert et al., 201034 | low | Retro  | 63 | Mean: 60 mos (18.8); range 1-6 yrs | CFQ | Mean 29.8 (18.4), %NR | CFQ >43 |

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| Nichol et al., 201550 | low | Pros | 644 (completed at least 1 assessment) | 1, 3, 6 mos | ALFI MMSE | 17.30% | <17 |
| Orbo et al., 201451 | low | Pros | 45 | 3 mos (114 days, range 80-131) | General cognitive ability (WASI); Memory (CVLT; Rey CF; WMS-3 DS); EF (D-Kefs Trail-making test, Color-Word, Verbal fluency); Psychomotor (GP) | Overall 44%; WASI 15.9%; CVLT 13.3%; Rey CF 30.8%; WMS -DS 9.8%; D-Kefs TMT 8.9%, color-word 15.4%, verbal fluency, 12.5%; grooved peg board 12.2% | Norms, 1.5 SDs  |
| Orbo et al., 201630 | low | Pros | 33 | cog 3 & 12 mos, QoL 12 mos | General cognitive ability (WASI); Memory (CVLT; Rey CF; WMS-3 DS; EF (D-Kefs Trail-making test, Color-Word, Verbal fluency); Psychomotor (GP) | Composite scores: Visual memory T1: 21%, T2: 10%; Verbal memory T1: 18%, T2: 15%; Psychomotor T1:3%, T2: 0; EF T1: 12%, T2 10%; WASI T1 and T2 12% | Norms, 1.5 SDs  |
| Orbo et al., 201532 | low | Pros | 42 | 3 months | Memory (CVLT, Rey CF); Executive (D-KEFs TMT, Color-Word); Psychomotor (GP) | CVLT 10-33%; Rey CF 17%, D-KEFs TMT 5-8%, Color-word 10%; Grooved pegboard 7-10% | Norms, 1.5 SDs  |
| Orbo et al., 201952 | low | Pros | 13 ohca; 19 controls | 3 months | Memory (CVLT, Rey CF); Executive (D-KEFs TMT); Psychomotor (GP) | Compared with healthy controls: significantly lower performance on verbal memory and psychomotor measures | NR |
| Orbo et al., 201817 | low | Pros | G1: 13, G2: 13; Controls: 19 | 3 months | Memory (CVLT) | Sig lower OHCA-unconsious arrival compared with conscious arrival/controls | NR |
| Polanowska et al., 201431 | mod | Pros | few days; 3 mos:21; 6 mos: 17; 12 mos: 14 | OHCA, 3, 6, 12 mos | General cognitive ability (ACE-R)Memory (RAVLT, DSF, BentonVRT);Attention (Trails A); EF (WCST, Trails B); Language (speech/naming); Visuo-spatial (Rey CF) | Overall 57.2%; Memory 64-94%; Attention 0-48%; EF 21-62%; Visuo-spatial 14-33%; Language 14-48%  | Norms |
| Rosen et al., 201424 | mod | Pros | OHCA=21; control = 21 | T1=2-4 days; T2=12-14 days; T3=45 days; T4=3 months; T5=1 year  | MMSE | 60% | <28  |
| Stamenova et al., 20185 | mod | Pros | OHCA=9, 8 for neuropsych: MI = 7 | 5 mos, one at 20 days, average: 46 months for MI; 27 mos for OHCA | General cognitive ability (WAIS-III MR); Visual processing (Hooper, Rey CF); Memory (Rey CF, CVLT, CANTAB-Paired Associate Learning, Camden Memory Test, WMS-III Verbal Paired Associates and Logical Memory); EF (Trails, PASAT, COWAT, CANTAB Intra-Extra Dimensional Set Shift, WAIS-III DS) | Sig difference between groups (OHCA lower than MI) on memory  | Norms |
| Sulzgruber et al., 201553 | low | Pros  | OHCA: 33; controls (age/ed/sex matched): 33 | 4 weeks post | Memory (RAVLT, WAIS-R DSB, red-pencil-test, WMS logical memory) | Sig difference between groups (OHCA lower than healthy controls) on immediate and delayed recall, working memory, prospective memory  | Raw scores by group |
| Tiainen et al., 200750 | low | Pros | hypothermia: 27; non: 18 | MMSE: day 14; cog tests: 3 months | Global cognitive function (MMSE); Memory (WMS-R logical memory; AVLT, RBMT); EF (Stroop, Trails B, verbal fluency); Processing Speed (WAIS-R digit-symbol, Trails A, Stroop-congruent, GP) | Overall: 33-56%; Learning and memory 24%; EF: 33%, 19% speed | Norms, 1.5 SDs; patient's intact if 70% (6/8) scores above cut-off; specific cog functions impaired if 50% of tests below cut-off  |
| Tiainen et al., 201554 | mod | Pros | n=41 | 6-8 mos, median 7 mos | General cognitive ability (WAIS-R: Similarities, Blocks, digit-symbol, visual search); Memory (WMS-R (logical passages, list learning); EF (Trails, Stroop, semantic fluency) | 51%, specific area NR | Norms, 1 SD; Impaired if performance on >1 test was below norms |
| Torgersen et al., 201055 | low | Retro | 26 | 13-28 mos (mean=20.4 mos) | Global cognitive function (MMSE); General cognitive ability (CANTAB motor screening test, delayed matching to sample, stockings, PAL) | 52%; deficits in EF and episodic memory compared with norm data | MMSE <24; Norms, 1.5 SD on at least 3 measures or 2 SDs on 2 measures (out of 10) |
| Wachelder et al., 200956 | low | Retro | 63 | 36 mos (18.8) | CFQ | 21% |  >/= 44 |
| Wilson et al., 201419 | low | Retro | 56 | 25.81 - 27.78 mos | DEX, EMQ-R | EMQ-R 9-16% | NR |

**Note:** Norms=normative data; SD = standard deviation; Pros = prospective design; Retro = retrospective design; MI=Myocardial Infarction

**Key for Measures:** ACE-R, Addenbrooke's Cognitive Examination-Revised; AVLT, Auditory Verbal Learning Test; BNT, Boston Naming Test; BT, Block tapping, Weschler Memory Scale; BVMT, Brief Visual Memory Test; BVRT, Benton Visual Retention Test; CANTAB, Cambridge Neuropsychological Test Automated Battery; CASI, Cognitive Abilities Screening Instrument; CFQ, Cognitive Failures Questionnaire; CMT, Camden Memory Test; CNB, Computerized Neurocognitive Battery; COWAT, Controlled oral word association test; CVLT, California Verbal Learning Test; DEX, Dysexecutive Questionnaire; D-KEFs, Delis-Kaplan Executive Function System; EMQ-R, Everyday Memory Questionnaire; FAB, Frontal Assessment Battery; HVOT, Hooper Visual Organisation Test; IQCODE/IQCODE-CA, Informant Questionnaire on Cognitive Decline in the Elderly-Cardiac Arrest; JOL, Judgement of Line Orientation; NAB, Neuropsychological Assessment Battery, NART/ANART, National Adult Reading Test; PAL, Paired Associates Learning; PASAT, Paced Auditory Serial Addition Test; PPV, Peabody Picture Vocabulary; RAVLT, Rey Auditory Verbal Learning Test; Rey CF, Rey-Osterrieth Complex Figure Test; RBMT, Rivermead Behavioural Memory Test; SDMT, Symbol digit modalities test; TICs, Telephone Interview for Cognitive Status; VF, Verbal Fluency; WAIS, Wechsler Adult Intelligence Scale: Dig-Sym, digit symbol, DS, Digit Span; WASI, Wechsler Abbreviated Scale of Intelligence; WCST, Wisconsin Card Sorting Test; WMS, Wechsler Memory Scale.

4. Discussion

Forty-three articles were identified that included cognitive assessment after OHCA. Following on from the review of 28 articles by Moulaert et al. in 20092, this review sought to identify progress in this area since 2006. Moulaert identified key challenges when attempting to generalize findings across studies including studies having a high risk of bias, low sample size, lack of a standard protocol, and not accounting for possible confounding factors. There has been some progress in our understanding of neurocognitive outcomes; however, issues persist in all these areas.

Whilst most studies had a low risk of bias overall, there remain concerns over the generalizability of findings given the sampling approaches and sample sizes used as well as the lack of reporting of effect sizes and power analyses. Findings from papers with low sample sizes need to be interpreted with caution. In addition, there are also possible confounding factors such as age, premorbid status, comorbidities, and treatment differences that may also reduce generalizability of findings to the broader OHCA population. The timing of the assessments varied considerably, from days to years after the OHCA. Criteria for selection were similar to those used in the prior review; however, this review included assessments conducted from hospital discharge rather than starting from 3 months. When comparing findings, the time of the assessment needs to be considered and future work should focus on looking at change over time. The premorbid characteristics of those being studied (cognitive reserve, pre-existing conditions, etc.), and how these influences neurocognitive outcomes following OHCA, merits further consideration. Cognitive reserve estimates may help to understand differences in outcome between individuals. When classifying survivors into severe and mild groups based on composite cognitive tests, it has been found that those in the more severe groups also have lower reading score, which can be used as a proxy measure of premorbid functione.g., 39, 43. Therefore, deficits in high reserve individuals may be masked and underestimated when not accounting for this reserve.

Studies that included both in- and out of hospital cardiac arrest were excluded if it was not possible to identify cognitive outcomes specific to the OHCA group. Whilst this was necessary because those with IHCA may differ in a substantive way to patients with OHCA, it also likely means that high quality studies that could add to our knowledge base were excluded. In future studies it would be valuable to differentiate outcomes between these two populations.

It is also crucial to consider how representative survivors participating in research are of the entire population they represent. Studies are likely to report education level and gender; however, it is not standard to report variables such as race, ethnicity and socioeconomic background which makes it difficult to assess the inclusivity and generalizability of the findings. This risk of selection bias has been discussed in other worke.g.,33,41. Survivors with poorer outcome may be excluded or unable to perform the neurocognitive tests while survivors with good outcome may not be identified due to non-granular instruments used (e.g., ceiling effects) that were not designed to be sensitive to subtle impairment or decline participation due to not experiencing any perceived problems in their cognitive function. These issues should be addressed in future work.

There continues to be a heterogenous approach to the domains of cognitive function assessed and the measures used. Even studies using the same measures often have varying levels of impairment reported. It is difficult to tell if this is due to a range of cognitive impairment after OHCA or to other factors such as the population included in the study, the timing of the assessment, or the treatment protocol used. In addition, the threshold for classifying patients as impaired varies across studies depending on the cut-off criteria adopted. For example, some studies have a cut-off score for impairment based on established test norms whereas others compare performance to population or patient normative data. Even within this latter category, there are discrepancies with some studies identifying cut-off criteria as performance 1 SD below the mean and others at 2-3 SDs below the norm. A greater degree of standardization in cognitive assessment following OHCA would allow different studies and treatments to be assessed and compared more effectively.

Neurocognitive impairment following OHCA is associated with lower societal participation, fatigue and restricted mobility22. Studies also report associations between neurocognitive impairment and depression19,22, while others do not38,47. Since the Moulaert et al (2009) review, the MoCA has been recommended by the European Resuscitation Council as a neurocognitive screening tool after CA53. The Core Outcome Set for Cardiac Arrest (COSCA) statement54 recommends that core outcomes in CA effectiveness studies should include survival, neurological function, and health-related quality of life, with neurological function measured by the mRS9 at hospital discharge, at 30 days, or both. Most studies included in this review were focused on neurocognitive function and performed after 30-days. The frequent neurocognitive problems identified in the studies of this review emphasise the need for a neurological screening at an early stage that could indicate neurocognitive impairment. Our findings are therefore in line with the COSCA58 recommendations. Furthermore, using measures such as the CPC and the mRS, whilst useful, lack sensitivity and specificity in relation to identifying areas of potentially subtle cognitive impairment, increasing the risk of both Type I and Type II errors. Including multi-dimensional measures of function decreases Type-II errors though potentially increases Type I error, especially as additional measures are added to a battery of tests. Thus, future work should endeavour to cast a wide net initially and then identify specific measures across areas of function to appropriately balance Type I and Type II errors when identifying neurocognitive decline associated with OHCA.

Specific recommendations for further neurocognitive instruments with acceptable psychometric properties assessing specific neurocognitive domains do not currently exist and are needed for use in clinical trials and where indicated in clinical practice.

5. Conclusions

The need for neurocognitive assessment that is more sensitive to a wide range of OHCA outcomes is clear. A standardized framework for evaluation should incorporate inclusive approaches to recruitment, information on premorbid status and comorbidities, and specific factors related to the cardiac arrest. This should be combined with a consistent and efficient approach to the assessment of memory, executive functions, and attention/processing that is related to, and predictive of, quality of life and daily function. Improved understanding of the optimal approach to assessment and interpretation of the subsequent findings will facilitate the development of recommendations for the standardized evaluation of neurocognitive outcomes following OHCA.

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**Appendix A: Search Approach and Terms:**

**Index Language Terms:**

Medical Subject Headings (MesH); Embase subject headings (biomed/life science) and key words

**Databases:**

Medline, Cinahl, PsychInfo, follow-up with Google Scholar

**Key words**:

|  |  |
| --- | --- |
| **POPULATION**  | **OUTCOMES**  |
| Heart arrest  | Cognitive function |
| Asystole  | Cognition disorders |
| Cardiac arrest  | Cognitive impairment |
| Cardiopulmonary arrest  | Neuropsychological assessment |
| Circulatory arrest  | Neuropsychological evaluation |
| Cardiac sudden death  | Neuropsychological test |
| Sudden cardiac death  | Neuropsychological function |
| Resuscitation  | Neurocognitive deficits |
| Cardiopulmonary resuscitation  | Neurocognitive assessment |
| CPR | Executive function |
| Out-of-hospital cardiac arrest  | Executive control |
|   | Executive attention |
|   | Working memory |
|   | Memory disorders |
|   | Attention |
|   | Concentration |

References

1. Gräsner JT, Herlitz J, Tjelmeland IB, Wnent J, Masterson S, Lilja G, Bein B, Böttiger BW, Rosell-Ortiz F, Nolan JP, Bossaert L. European Resuscitation Council Guidelines 2021: Epidemiology of cardiac arrest in Europe. Resuscitation. 2021 Apr 1;161:61-79. https://doi.org/10.1016/j.resuscitation.2021.02.007
2. Moulaert VR, Verbunt JA, van Heugten CM, Wade DT. Cognitive impairments in survivors of out-of-hospital cardiac arrest: a systematic review. Resuscitation. 2009 Mar 1;80(3):297-305. https://doi.org/10.1016/j.resuscitation.2008.10.034
3. Mędrzycka-Dąbrowska WA, Czyż-Szybenbejl K, Kwiecień-Jaguś K, Lewandowska K. Prediction of cognitive dysfunction after resuscitation–a systematic review. Advances in Interventional Cardiology/Postepy Kariol Interwencyjnej. 2018;14(3):225., 2018. https://dx.doi.org/10.5114%2Faic.2018.78324
4. Byron-Alhassan A, Tulloch HE, Collins B, Quinlan B, Fang Z, Chakraborty S, Le May M, Duchesne L, Smith AM. Exploratory Analyses of Cerebral Gray Matter Volumes After Out-of-Hospital Cardiac Arrest in Good Outcome Survivors. Front Psychol. 2020 May 6;11:856. https://doi.org/10.3389/fpsyg.2020.00856
5. Stamenova V, Nicola R, Aharon-Peretz J, Goldsher D, Kapeliovich M, Gilboa A. Long-term effects of brief hypoxia due to cardiac arrest: Hippocampal reductions and memory deficits. Resuscitation 2018:65–71. <https://doi.org/10.1016/j.resuscitation.2018.02.016>.
6. Beesems SG, Wittebrood KM, de Haan RJ, Koster RW. Cognitive function and quality of life after successful resuscitation from cardiac arrest. Resuscitation. 2014 Sep 1;85(9):1269-74. https://doi.org/10.1016/j.resuscitation.2014.05.027
7. Jacobs I, Nadkarni V, Bahr J, Berg RA, Billi JE, Bossaert L, Cassan P, Coovadia A, D'este K, Finn J, Halperin H. Update and simplification of the Utstein templates for resuscitation registries: A statement for healthcare professionals from a task force of the International Liaison Committee on Resuscitation. Resuscitation. 2004;63(3):233-49. https://doi.org/10.1161/01.cir.0000147236.85306.15
8. Teasdale G, Jennett B. Assessment of coma and impaired consciousness: a practical scale. The Lancet. 1974 Jul 13;304(7872):81-4. https://doi.org/10.1016/s0140-6736(74)91639-0
9. Van Swieten JC, Koudstaal PJ, Visser MC, Schouten HJ, Van Gijn J. Interobserver agreement for the assessment of handicap in stroke patients. Stroke. 1988 May;19(5):604-7.
10. Downs SH, Black N. (1998) The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. J Epidemiol Community Health 52:377–384.
11. Ferro MA, Speechley KN. Depressive symptoms among mothers of children with epilepsy: a review of prevalence, associated factors, and impact on children. Epilepsia. 2009 Nov;50(11):2344-54.
12. Gates S, Lall R, Quinn T, Deakin CD, Cooke MW, Horton J, Lamb SE, Slowther AM, Woollard M, Carson A, Smyth M. Prehospital randomised assessment of a mechanical compression device in out-of-hospital cardiac arrest (PARAMEDIC): a pragmatic, cluster randomised trial and economic evaluation. Health technology assessment (Winchester, England). 2017 Mar 1;21(11):1-76.
13. Ji C, Lall R, Quinn T, Kaye C, Haywood K, Horton J, et al. Post-admission outcomes of participants in the PARAMEDIC trial: A cluster randomised trial of mechanical or manual chest compressions. Resuscitation 2017;118:82–8. <https://doi.org/10.1016/j.resuscitation.2017.06.026>.
14. Aufderheide TP, Frascone RJ, Wayne MA, Mahoney BD, Swor RA, Domeier RM, et al. Standard cardiopulmonary resuscitation versus active compression-decompression cardiopulmonary resuscitation with augmentation of negative intrathoracic pressure for out-of-hospital cardiac arrest: a randomised trial. Lancet 2011;377:301–11. [https://doi.org/10.1016/S0140-6736(10)62103-4](https://doi.org/10.1016/S0140-6736%2810%2962103-4).
15. Bro-Jeppesen J, Kjaergaard J, Horsted TI, Wanscher MC, Nielsen S, Rasmussen LS, et al. The impact of therapeutic hypothermia on neurological function and quality of life after cardiac arrest. Resuscitation 2009;80:171–6. https://doi.org/10.1016/j.resuscitation.2008.09.009.
16. Evald L, Brønnick K, Duez CHV, Grejs AM, Jeppesen AN, Søreide E, et al. Prolonged targeted temperature management reduces memory retrieval deficits six months post-cardiac arrest: A randomised controlled trial. Resuscitation 2019;134:1–9. https://doi.org/10.1016/j.resuscitation.2018.12.002.
17. Ørbo MC, Vangberg TR, Tande P, Anke A, Aslaksen PM. Memory performance, global cerebral volumes and hippocampal subfield volumes in long-term survivors of Out-of-Hospital Cardiac Arrest. Resuscitation 2018:21–8. https://doi.org/10.1016/j.resuscitation.2018.02.011.
18. Torgersen J, Strand K, Bjelland TW, Klepstad P, Kvåle R, Søreide E, et al. Cognitive dysfunction and health-related quality of life after a cardiac arrest and therapeutic hypothermia. Acta Anaesth Scand 2010;54:721–8. https://doi.org/10.1111/j.1399-6576.2010.02219.x.
19. Wilson M, Staniforth A, Till R, das Nair R, Vesey P. The psychosocial outcomes of anoxic brain injury following cardiac arrest. Resuscitation 2014;85:795–800. https://doi.org/10.1016/j.resuscitation.2014.02.008.
20. Harve H, Tiainen M, Poutiainen E, Maunu M, Kajaste S, Roine RO, et al. The functional status and perceived quality of life in long-term survivors of out-of-hospital cardiac arrest. Acta Anaesth Scand 2007;51:206–9.
21. Andersson A-E, Rosén H, Sunnerhagen KS. Life after cardiac arrest: A very long term follow up. Resuscitation 2015;91:99–103. <https://doi.org/10.1016/j.resuscitation.2015.01.009>.
22. Lilja G, Nielsen N, Bro-Jeppesen J, Dunford H, Friberg H, Hofgren C, et al. Return to Work and Participation in Society After Out-of-Hospital Cardiac Arrest. Circ-Cardiovasc Qual 2018;11:e003566–e003566. https://doi.org/10.1161/CIRCOUTCOMES.117.003566.
23. Fugate JE, Moore SA, Knopman DS, Claassen DO, Wijdicks EFM, White RD, et al. Cognitive outcomes of patients undergoing therapeutic hypothermia after cardiac arrest. Neurology 2013;81:40–5. <https://doi.org/10.1212/WNL.0b013e318297ee7e>.
24. Rosén C, Rosén H, Andreasson U, Bremell D, Bremler R, Hagberg L, et al. Cerebrospinal fluid biomarkers in cardiac arrest survivors. Resuscitation 2014;85:227–32. https://doi.org/10.1016/j.resuscitation.2013.10.032.
25. Folstein MF, Folstein SE, McHugh PR. Mini-mental state: A practical method for grading the cognitive state of patients for the clinician. J Psychiatr Res. 1975 Nov 1;12(3):189-98.
26. Roccaforte WH, Burke WJ, Bayer BL, Wengel SP. Validation of a telephone version of the Mini‐Mental State Examination. J Am Geriatr Soc. 1992 Jul;40(7):697-702. https://doi.org/10.1111/j.1532-5415.1992.tb01962.x
27. Nasreddine ZS, Phillips NA, Bédirian V, Charbonneau S, Whitehead V, Collin I, Cummings JL, Chertkow H. The Montreal Cognitive Assessment, MoCA: a brief screening tool for mild cognitive impairment. J Am Geriatr Soc. 2005 Apr;53(4):695-9. https://doi.org/10.1111/j.1532-5415.2005.53221.x
28. Heradstveit B, Larsson E-M, Skeidsvoll H, Hammersborg S-M, Wentzel-Larsen T, Guttormsen AB, et al. Repeated magnetic resonance imaging and cerebral performance after cardiac arrest--a pilot study. Resuscitation 2011;82:549–55. https://doi.org/10.1016/j.resuscitation.2011.01.018.
29. Caro-Codón J, Rey JR, Lopez-de-Sa E, González Fernández Ó, Rosillo SO, Armada E, et al. Long-term neurological outcomes in out-of-hospital cardiac arrest patients treated with targeted-temperature management. Resuscitation 2018;133:33–9. <https://doi.org/10.1016/j.resuscitation.2018.09.015>.
30. Ørbo M, Aslaksen PM, Larsby K, Schäfer C, Tande P, Anke A. Alterations in cognitive outcome between 3 and 12 months in survivors of out-of-hospital cardiac arrest. Resuscitation 2016;105:92–9. <https://doi.org/10.1016/j.resuscitation.2016.05.017>.
31. Polanowska KE, Sarzyńska-Długosz IM, Paprot AE, Sikorska Ś, Seniów JB, Karpiński G, et al. Neuropsychological and neurological sequelae of out-of-hospital cardiac arrest and the estimated need for neurorehabilitation: a prospective pilot study. Polish Heart Journal / Kardiologia Polska 2014;72:814–22. https://doi.org/10.5603/KP.a2014.0087.
32. Ørbo M, Aslaksen PM, Larsby K, Schäfer C, Tande P, Vangberg TR, et al. Relevance of Cognition to Health-Related Quality of Life in Good-Outcome Survivors of Out-Of-Hospital Cardiac Arrest. Journal of Rehabilitation Medicine (Stiftelsen Rehabiliteringsinformation) 2015;47:860–6. https://doi.org/10.2340/16501977-1998.
33. Lilja G, Nilsson G, Nielsen N, Friberg H, Hassager C, Koopmans M, et al. Anxiety and depression among out-of-hospital cardiac arrest survivors. Resuscitation 2015;97:68–75. https://doi.org/10.1016/j.resuscitation.2015.09.389.
34. Moulaert V, Wachelder EM, Verbunt JA, Wade DT, van Heugten C M. Determinants of quality of life in survivors of cardiac arrest. J Rehabil Med 2010;42:553–8. <https://doi.org/10.2340/16501977-0547>.
35. Cronberg T, Lilja G, Horn J, Kjaergaard J, Wise MP, Pellis T, et al. Neurologic function and health-related quality of life in patients following targeted temperature management at 33°C vs 36°C after out-of-hospital cardiac arrest: A randomized clinical trial. JAMA Neurology 2015;72:634–41. <https://doi.org/10.1001/jamaneurol.2015.0169>.
36. Blennow Nordström E, Lilja G, Årestedt K, Friberg H, Nielsen N, Vestberg S, et al. Validity of the IQCODE-CA: An informant questionnaire on cognitive decline modified for a cardiac arrest population. Resuscitation 2017;118:8–14. <https://doi.org/10.1016/j.resuscitation.2017.06.012>.
37. Grand J, Lilja G, Kjaergaard J, Bro-Jeppesen J, Friberg H, Wanscher M, et al. Arterial blood pressure during targeted temperature management after out-of-hospital cardiac arrest and association with brain injury and long-term cognitive function. Eur Heart J. Acute Cardiovasc Care 2019:2048872619860804–2048872619860804. <https://doi.org/10.1177/2048872619860804>.
38. Grubb NR, Simpson C, Sherwood RA, Abraha HD, Cobbe SM, O’Carroll R E, et al. Prediction of cognitive dysfunction after resuscitation from out-of-hospital cardiac arrest using serum neuron-specific enolase and protein S-100. Heart (British Cardiac Society) 2007;93:1268–73.
39. Alexander MP, Lafleche G, Schnyer D, Lim C, Verfaellie M. Cognitive and functional outcome after out of hospital cardiac arrest. J Int Neuropsychol Soc 2011;17:364–8. <https://doi.org/10.1017/S1355617710001633>.
40. Brønnick K, Evald L, Duez CH, Grejs AM, Jeppesen AN, Kirkegaard H, Nielsen JF, Søreide E. Biomarker prognostication of cognitive impairment may be feasible even in out-of hospital cardical arrest survivors with good neurological outcome. Resuscitation. 2021 May 1;162:396-402. <https://doi.org/10.1016/j.resuscitation.2021.02.025>
41. Byron-Alhassan A, Collins B, Bedard M, Quinlan B, Le May M, Duchesne L, Osborne C, Wells G, Smith AM, Tulloch HE. Cognitive dysfunction after out-of-hospital cardiac arrest: Rate of impairment and clinical predictors. Resuscitation. 2021 May 12. <https://doi.org/10.1016/j.resuscitation.2021.05.002>
42. Byron-Alhassan A, Tulloch HE, Collins B, Quinlan B, Fang Z, Chakraborty S, Le May M, Duchesne L, Smith AM. Exploratory analyses of cerebral gray matter volumes after out-of-hospital cardiac arrest in good outcome survivors. Frontiers in Psychology. 2020 May 6;11:856. <https://doi.org/10.3389/fpsyg.2020.00856>
43. Davies SE, Rhys M, Voss S, Greenwood R, Thomas M, Benger JR. Psychological wellbeing in survivors of cardiac arrest, and its relationship to neurocognitive function. Resuscitation 2017:22–5. <https://doi.org/10.1016/j.resuscitation.2016.11.004>.
44. Evald L, Brønnick K, Duez CH, Grejs AM, Jeppesen AN, Søreide E, Kirkegaard H, Nielsen JF. Younger age is associated with higher levels of self-reported affective and cognitive sequelae six months post-cardiac arrest. Resuscitation. 2021 Apr 19. <https://doi.org/10.1016/j.resuscitation.2021.04.009>
45. Juan E, De Lucia M, Beaud V, Oddo M, Rusca M, Viceic D, et al. How Do You Feel? Subjective Perception of Recovery as a Reliable Surrogate of Cognitive and Functional Outcome in Cardiac Arrest Survivors. Crit Care Med 2018;46:e286–93. <https://doi.org/10.1097/CCM.0000000000002946>.
46. Lilja G, Nielsen N, Friberg H, Horn J, Kjaergaard J, Nilsson F, et al. Cognitive Function in Survivors of Out-of-Hospital Cardiac Arrest After Target Temperature Management at 33°C Versus 36°C. Circulation 2015;131:1340–9. <https://doi.org/10.1161/CIRCULATIONAHA.114.014414>.
47. Lim C, Verfaellie M, Schnyer D, Lafleche G, Alexander MP. Recovery, Long-Term Cognitive Outcome and Quality of Life Following Out-Of-Hospital Cardiac Arrest. Journal of Rehabilitation Medicine (Stiftelsen Rehabiliteringsinformation) 2014;46:691–7. https://doi.org/10.2340/16501977-1816.
48. Longstreth W Jr, Nichol G, Van Ottingham L, Hallstrom AP, Longstreth WTJ, Nichol G, et al. Two simple questions to assess neurologic outcomes at 3 months after out-of-hospital cardiac arrest: experience from the public access defibrillation trial. Resuscitation 2010;81:530–3. https://doi.org/10.1016/j.resuscitation.2010.01.011.
49. Mateen FJ, Josephs KA, Trenerry MR, Felmlee-Devine M, Weaver AL, Carone M, et al. Long-term cognitive outcomes following out-of-hospital cardiac arrest: A population-based study. Neurology 2011;77:1438–45. <https://doi.org/10.1212/WNL.0b013e318232ab33>.
50. Nichol G, Guffey D, Stiell IG, Leroux B, Cheskes S, Idris A, et al. Post-discharge outcomes after resuscitation from out-of-hospital cardiac arrest: A ROC PRIMED substudy. Resuscitation 2015;93:74–81. <https://doi.org/10.1016/j.resuscitation.2015.05.011>.
51. Ørbo M, Aslaksen PM, Larsby K, Norli L, Schäfer C, Tande P, et al. Determinants of cognitive outcome in survivors of out-of-hospital cardiac arrest. Resuscitation 2014;85:1462–8. https://doi.org/10.1016/j.resuscitation.2014.08.010.
52. Ørbo M C, Aslaksen PM, Anke A, Tande P, Vangberg TR. Cortical Thickness and Cognitive Performance After Out-of-Hospital Cardiac Arrest. Neurorehabil Neural Repair  2019;33:296–306. https://doi.org/10.1177/1545968319834904.
53. Sulzgruber P, Kliegel A, Wandaller C, Uray T, Losert H, Laggner AN, et al. Survivors of cardiac arrest with good neurological outcome show considerable impairments of memory functioning. Resuscitation 2015;88:120–5. https://doi.org/10.1016/j.resuscitation.2014.11.009.
54. Tiainen M, Poutiainen E, Kovala T, Takkunen O, Häppölä O, Roine RO, et al. Cognitive and neurophysiological outcome of cardiac arrest survivors treated with therapeutic hypothermia. Stroke 2007;38:2303–8.
55. Tiainen M, Poutiainen E, Oksanen T, Kaukonen K-M, Pettilä V, Skrifvars M, et al. Functional outcome, cognition and quality of life after out-of-hospital cardiac arrest and therapeutic hypothermia: data from a randomized controlled trial. Scand J Trauma, Resusc Emerg Med 2015;23:12–12. <https://doi.org/10.1186/s13049-014-0084-9>.
56. Wachelder EM, Moulaert VRMP, van Heugten C, Verbunt JA, Bekkers SCAM, Wade DT. Life after survival: long-term daily functioning and quality of life after an out-of-hospital cardiac arrest. Resuscitation 2009;80:517–22. <https://doi.org/10.1016/j.resuscitation.2009.01.020>
57. Nolan, J.P., Sandroni, C., Böttiger, B.W. *et al.* European Resuscitation Council and European Society of Intensive Care Medicine guidelines 2021: post-resuscitation care. *Intensive Care Med* **47,**369–421 (2021). <https://doi.org/10.1007/s00134-021-06368-4>
58. Haywood K, Whitehead L, Nadkarni VM, Achana F, Beesems S, Böttiger BW, Brooks A, Castrén M, Ong ME, Hazinski MF, Koster RW. COSCA (Core Outcome Set for Cardiac Arrest) in adults: an advisory statement from the International Liaison Committee on Resuscitation. Circulation. 2018 May 29;137(22):e783-801. <https://doi.org/10.1161/CIR.0000000000000562>