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Abstract

Objective: To systematically examine the effect of dehydration on health outcomes, identify associated financial costs and consider impacts on cognitive performance in older adults.

Design: A systematic review of English-language articles via OVID using MEDLINE, PsychINFO, EMBASE, and others, to March 2018. Included studies examined the relationship between hydration status and health, care costs or cognitive outcome.

Setting: Cross sectional and cohort data from studies reporting on dehydration in older adults.

Participants: Adults aged 60 years and older.

Measurements: Independent quality ratings were assessed for all extracted articles.

Results: Of 1684 articles screened, 18 papers (N = 33,707) met inclusion criteria. Participants were recruited from hospital settings, medical long-term care centres and the community dwelling population. Data were synthesised using a narrative summary. Mortality rates were higher in dehydrated patients. Furthermore, health outcomes, including frailty, bradyarrhythmia, transient ischemic attacks, oral health and surgery recovery are linked to and worsened by dehydration. Length of hospital stay, either as a principal or secondary diagnosis, is greater in those with dehydration, compared to those who are euhydrated. Finally, neurocognitive functioning may be impacted by dehydration. There are issues with study design, inconsistency in hydration status measurement and different measures used for outcome assessment.

Conclusion: Dehydration in older people is associated with increased mortality, poorer course of illness and increased costs for health services. In addition, there is some, but sparse evidence that dehydration in older people is linked to poorer cognitive performance. Intervention studies should test strategies for reducing dehydration in older adults.

Keywords

Dehydration, Older adults, Healthcare, Cognitive Performance

1 Introduction

The proportion of older people in the world population is rapidly increasing. While 8% of people were 65 years or older in 2010, estimates indicate this will double to 16% in 2050 (National Institute on Aging, National Institues of Health, U.S. Department of Health and Human Services, & World Health Organisation, 2011). The ageing of large cohorts and improved longevity is increasing the demands on health services and will have crucial implications for health policy development (National Institute on Aging et al., 2011). For example, the number of inpatient stays for the over 75s has increased by 50% between 2001 and 2013-14 (Licchetta & Stelmach, 2016). Age-related changes in cognition can affect daily functioning (Harada, Natelson Love, & Triebel, 2013) and are important to understand in order to achieve successful cognitive aging. Dehydration has been linked to poorer health outcomes (Benelam & Wyness, 2010; El-Sharkawy, Sahota, & Lobo, 2015) and worsened cognitive performance in younger adults and children (Benton, Jenkins, Watkins, & Young, 2016; Benton & Young, 2015; Edmonds et al., 2017; Edmonds, Harte, & Gardner, 2018). Older adults are at higher risk of developing dehydration (Bennett, 2000; Hooper et al., 2016) and dehydration is more prevalent in older adults (Stookey, Pieper, & Cohen, 2005). However, the effect of dehydration in older people on health, costs of healthcare and maintaining optimal cognitive function has not been systematically reviewed.

The human body is kept in a state of euhydration by homeostatic management of water intake and water loss. When water loss exceeds water intake, dehydration occurs. Older adults are at particular risk of dehydration (Bennett, 2000), due to a number of factors, including physical changes such as age-related decreases in sensitivity to thirst (Kenney & Chiu, 2000; Mentes, 2006), decreases in total body water resulting in greater propensity for dehydration with smaller changes in fluid intake (Bennett, 2000), changes in kidney function that render the kidneys less able to conserve body water (Silva, 2005), medications which affect body water (Mentes, 2006), as well as problems with mobility (Ferry, 2005). In addition, situational and psychological factors include difficulty with access to drinks (Ferry, 2005) and fear of incontinence (Abdallah, Remington, Houde, Zhan, & Devereaux Melillio, 2009) that affect the amount consumed.

There is a wide range of prevalence estimates of dehydration in older adults depending on the subgroup being measured. The prevalence ranges from over one third of older adults who were admitted to hospital as emergencies (El-Sharkawy, Sahota, et al., 2015), to 20% (Hooper et al., 2016) to 88% (O'Neill et al., 1990) of older adults in care homes, to 60% of community dwelling older adults (Stookey et al., 2005). Estimates of dehydration prevlance may also vary as a result of methodological differences in measuring and defining dehydration (Bak, Tsiami, & Greene, 2017; Stookey et al., 2005).

Dehydration is related to negative health outcomes, such as falls, constipation, infections (Mentes, 2006) and frailty (McCrow, Morton, Travers, Harvey, & Eeles, 2016). Importantly, being dehydrated at the time of hospital admission is associated with increased morbidity and mortality (El-Sharkawy, Watson, et al., 2015), which suggests that it may worsen the course of illness. Furthermore, dehydration itself may be associated with substantial costs to healthcare systems as a consequence of longer hospital stays and increased readmission rates (Frangeskou, Lopez-Valcarcel, & Serra-Majem, 2015; Warren et al., 1994; Xiao, Barber, & Campbell, 2004).

Dehydration has also been linked to poorer cognitive performance in adults and children

(Masento, Golightly, Field, Butler, & van Reekum, 2014; Wittbrodt & Millard-Stafford, 2018). For example, research in adults has reported that a water loss of more than 2% of body mass (a commonly used indicator of dehydration) negatively affects cognitive performance (D'Anci, Vibhakar, Kanter, Mahoney, & Taylor, 2009; Gopinathan, Pichan, & Sharma, 1988; Sharma, Sridharan, Pichan, & Panwar, 1986), including memory, attention, mathematical calculation and perceptual motor speed. Although the degree of dehydration experienced by many in everyday life is mild and transient (Benton et al., 2015), and might be presumed unlikely to affect cognitive function, recent work has suggested that even a minor degree of dehydration (<1% loss of body mass) is associated with worsened cognition (Benton et al., 2016). In children who, like older adults, are a population at higher risk of dehydration, dehydration has been linked to worsened memory performance (as assessed by digit span) (Bar-David, Urkin, Landau, Bar-David, & Pilpel, 2009; Edmonds & Burford, 2009; Edmonds et al., 2017; Fadda et al., 2012). If, as the literature would suggest, dehydration is more prevalent in older adults, it is possible that dehydration may be a hitherto unrecognised risk factor for age-related cognitive impairments.

Despite the estimated high prevalence of dehydration in older adults, the effects on health and cognition have not been systematically reviewed. A previous systematic review had examined the effect of dehydration on oral health in older adults (Hodgkinson, Evans, & Wood, 2003). The present systematic review examines the effect of dehydration on health outcomes, financial costs, and cognitive performance in adults aged 60 years or over.

2 METHODS

2.1 Database search and selection procedures

We employed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol (Moher, Liberati, Tetzlaff, Altman, & Grp, 2009) to select relevant studies. The studies were selected for review using PICOS (population, intervention, comparison group, outcome, study design) criteria (Table 1). Studies were included if they satisfied the following criteria: individuals with a mean age of 60 years old or above; analysis of the relationship between hydration status and health or cognitive outcome or costs of care; original studies published in peer-reviewed journals; and English language. Exclusion criteria were: single-case studies or descriptive multiple-case studies; studies on hypo/hypernatremia, or fluid balance/homeostasis that did not explicitly mention dehydration.

Table 1. PICOS criteria for inclusion of studies

Parameter	**Criteria**
Population	Human participants aged 60 years or over
Intervention	Dehydration
Comparison	Euhydration
Outcome	Health-related outcomes, Costs of care, Cognitive performance
Study design	Original data from any study design. Excluded designs were single-case studies or descriptive multiple-case studies; studies on hypo/hypernatremia, or fluid balance/homeostasis that did not explicitly mention dehydration

Search terms were grouped in 2 categories: 1) hydration: hydrat*, dehydrat*, re-hydrat*, rehydrat*, water, fluid, hypernatrem*, hyponatrem*. 2) old age geriatric, senile, institutionalized adult*, institutionalised adult*, elder*, older, old age, nursing home, aging.

Truncated words allowed inclusion of all the variations of the root word. The Boolean Operator “OR” was adopted to separate the terms within each category, while “AND” was used to combine the two categories.

The search was performed up to March 2018 through OVID in the following databases: Ovid MEDLINE(R) Daily and Ovid MEDLINE(R) 1946 to Present; Epub Ahead of Print, In-Process & Other Non-Indexed Citations; PsycARTICLES Full Text; PsycINFO 1806 to March Week 2 2018; Journals@Ovid Full Text March 16, 2018; Your Journals@Ovid; Global Health 1973 to 2016 Week 29; HMIC Health Management Information Consortium 1979 to May 2016; International Pharmaceutical Abstracts 1970 to July 2016; and Embase Classic+Embase 1947 to 2016 August 01. Reference lists of included papers and reviews on dehydration in older adults were reviewed. Authors were contacted if the full-text of articles could not be accessed, as well as for clarifications and unpublished data.

Variables in the database were determined both a priori and as relevant variables were identified during the process of data extraction. Three sets of variables were identified: 1) general health outcomes 2) financial burden 3) cognitive outcomes.

2.2 Data analysis

Due to the heterogeneity of outcome measures and statistical methods adopted by the included studies, data are reported through a narrative summary. Where possible, mean values of sample demographics, prevalance of dehydration and relevant outcomes (e.g mortality) were calculated, as well as comparisons among different levels of hydration, and between dehydrated versus healthy older adults

2.3 Assessment of reporting strength

Study quality was assessed using a ten question assessment tool that employed dichotomous ratings of 0 or 1. Two authors independently assessed the studies and agreed their ratings. Our assessment tool was based on a systematic review of quality assessment tools for observational studies (Sanderson, Tatt, & Higgins, 2007) that were suitable for case-control, cohort and cross-sectional studies and not developed solely for the purpose of one particular study. Our tool adapted the most common factors to the purpose of the present study. We also introduced items from an assessment tool previously developed by one of the authors (Foglia, Schoeler, Klamerus, Morgan, & Bhattacharyya, 2017). Reporting strength was judged through 10 questions on the following factors: sample (including assessment of sampling bias, sample size and loss of data); design; control group; assessment of distorting influences and confounding variables; measurements of dehydration (including number of measures used, frequency of assessment and source of data) and outcome measures.

3 RESULTS

The database searches retrieved a total of 2198 records, which was reduced to 1684 after duplicates were removed (PRISMA flowchart - Figure 1). Of these, 276 were identified as relevant on the basis of the title and publication type. The abstracts of 276 papers were screened and 179 papers were excluded. Of the 179 excluded papers, 75 examined risk factors for dehydration, rather than observed effects of dehydration, 48 were solely focused on measurement of dehydration, 43 had outcomes irrelevant for the current review (e.g. biomarkers for dehydration) and the full text of 13 could not be located. The full text of 97 papers were examined and the reasons for exclusion included: on hyponatremia (n = 33), not suitable hydration variable (e.g. continence) (n = 8), outcome variable outside the remit of the review (n = 27), participant age < 60 years (n = 5), on hypernatremia (n = 9). A total of 18 studies met our inclusion and exclusion criteria and were included in the review (Ackland et al., 2008; Chan et al., 2018; El-Sharkawy, Watson, et al., 2015; Hooper, 2016; Johnson, Waldreus, Hahn, Stenström, & Sjöstrand, 2015; Khan, Hossain, Dashti, & Muthukumar, 2012; McCrow et al., 2016; Mukand, Cai, Zielinski, Danish, & Berman, 2003; Palmisano et al., 2014; Rodriguez et al., 2009; Seymour, Henschke, Cape, & Campbell, 1980; Ship & Fischer, 1997; Suhr, Hall, Patterson, & Niinisto, 2004; Suhr, Patterson, Austin, & Heffner, 2010; Wakefield, Mentes, Holman, & Culp, 2008; Warren et al., 1994; Weinberg et al., 1994; Xiao et al., 2004).

Figure 1 about here

3.1 Study characteristics

3.1.1 Studies on outcome of dehydration

The eighteen studies that met the inclusion criteria were drawn from 6 different countries (Australia, Canada, China, Italy, Sweden, UK, USA – see Tables 2 and 3). Sample sizes ranged from 21 to 31077, median n = 184. Participants were predominately female (67.8%), with a mean age of 80 years (weighted meanscalculated from all studies with the exception of one,(Warren et al., 1994) for which detailed data were not reported; Table 2).

Table 2. Study characteristics

Study – first author, reference, location	Sample size[a]	Gender (% males)	Mean Age (years)	Setting	Design/ Sample characteristics
Ackland, 2008 (UK)	52	59.6%	62.2	Hospital	Prospective cohort study comparing outcome of Patients hospitalized for colonoscopy, involving bowel preparation and thus dehydration (n=38) vs sigmoidoscopy (n=14)
Chan, 2018 (China)	216	36.9%	81.3	Hospital	Retrospective audit of hospital admissions for planned orthopaedic surgery, comparing euhydrated (n = 169) and dehydrated groups (n = 47)
El-Sharkawy, 2015 (UK)	187	53.5%	81.6	Hospital	Prospective cohort study of acute hospital admissions (emergency) comparing outcome of dehydrated (n=69) vs euhydrated (n=118) patients
Hooper, 2016 (UK)	188	34.0%	85.7	Long-term care	Correlational design examining the relationship between hydration status and cognitive, functional, and health-based risk factors
Johnson, 2015 (Sweden)	256	37.3%	81.9	Hospital	Prospective cohort study of consecutive hospital admissions of patients with high (i.e. Dehydration, n=39) and low (n=215) fluid retention index
Khan, 2012 (UK)	467	27.4%	79.6	Hospital	Retrospective audit of hospital admissions for fractured hip comparing incidence of dehydration between re-admitted and non re-admitted patients
McCrow, 2016	44	75.4%	81	Hospital	Prospective cohort study of hospital admissions examining the relationship between dehydration, frailty and cognitive impairment

(Australia)					
Mukand, 2003 (USA)	39	25.6%	78	Rehabilitiation center	Prospective pilot study comparing rehabilitation outcome of orthopedic patients with azotemia(n=21), orthostasis (n=18) or both (n=10)
Palmisano 2014 (Italy)	79	40.5%	81.6	Hospital	Prospective cohort study of outcome of patients with bradyarrhythmia admitted in hot (dehydration, n=33) vs cooler months (n=46)
Rodriguez, 2009 (USA)	428	50.0%	62.2	Hospital	Case-control retrospective audit of prevalence of dehydration in hospital discharges with (n=214) and without (n=214) ischemic stroke or transient ischemic attack
Seymour, 1980 (Canada)	68	42.6%	81.2	Hospital	Prospective cohort study examining the association between dehydration and mental state in patients hospitalized as emergencies.
Ship, 1997 (USA)	24 (of which 12 not elderly)	50.0%[b]	69.9[b]	Community	Intervention study examining changes in parodit salivary flow rates after inducing dehydration and re-hydration in healthy volunteers
Suhr, 2004 (USA)	28	21.4%	63.7	Community	Case control intervention study on the association between hydration status and psychomotor processing speed and memory performance in healthy individuals who were asked to abstain from drinking (n=14) vs those who could drink normally (n=14)
Suhr, 2010 (USA)	21	0.0%	60.3	Community	Correlational design examining the relationship between hydration status and declarative and working memory in elderly community dwelling women
Wakefield,	180	100%	65	Hospital	Case-control study examining outcome of hyponatremic patients[c] (n=17) vs patients with

2008 (USA)					volume depletion (n=72) vs controls (n=91)
Warren, 1994 (USA)	286	N/A[d]	N/A (range: 65-99)	Hospital	Retrospective audit on outcome of admissions with dehydration
Weinberg, 1994 (USA)	79	91.0%	75	Hospital	Prospective cohort study on prevalence of dehydration and outcome in patients with acute febrile episodes (n=42) and comparison with randomly selected control (n=37)
Xiao, 2004 (USA)	31077	31.1%	80.4	Hospital	Retrospective audit on outcome of admissions for dehydration

[a] sample size refers to the sample on which analysis was conducted, i.e. Excluding missing data

[b] data are referred to the elderly sub-group only

[c] hyponatremic patients were included as the study included dehydrated patients

[d] no information on gender, but gender (and age) controlled for in analysis

3.1.2 Settings

Participants were recruited from hospital settings (13 studies, n (range) = 44 – 31,077 participants) (Ackland et al., 2008; Chan et al., 2018; El-Sharkawy, Watson, et al., 2015; Johnson et al., 2015; Khan et al., 2012; McCrow et al., 2016; Palmisano et al., 2014; Rodriguez et al., 2009; Seymour et al., 1980; Wakefield et al., 2008; Warren et al., 1994; Weinberg et al., 1994; Xiao et al., 2004), from medical long-term care or rehabilitation centres (2 studies, n (range) = 39 - 188 participants) (Hooper et al., 2016; Mukand et al., 2003), and community-dwelling population (3 studies, n (range) = 21 - 28 participants) (Ship & Fischer, 1997; Suhr et al., 2004, 2010). For those in hospital or medical/rehabilitation samples, the reasons for care were as follows: colonoscopy or sigmondoscopy,(Ackland et al., 2008) fractured hip or other orthopedic problems (Chan et al., 2018; Khan et al., 2012; Mukand et al., 2003), bradyarrhythmia (Palmisano et al., 2014), ischemic stroke or transient ischemic attack (Rodriguez et al., 2009), acute febrile episode (Weinberg et al., 1994), volume depletion as a principal diagnosis (Wakefield et al., 2008; Warren et al., 1994; Xiao et al., 2004) and general admissions for any cause (El-Sharkawy, Watson, et al., 2015; Johnson et al., 2015; McCrow et al., 2016; Seymour et al., 1980).

Eight studies were prospective cohort studies assessing the effects of dehydration on health outomes, healthcare costs or cognitive performance at follow-up in the elderly (Ackland et al., 2008; El-Sharkawy, Watson, et al., 2015; Johnson et al., 2015; McCrow et al., 2016; Mukand et al., 2003; Palmisano et al., 2014; Seymour et al., 1980; Weinberg et al., 1994); 6 studies used a retrospective design (Chan et al., 2018; Khan et al., 2012; Rodriguez et al., 2009; Wakefield et al., 2008; Warren et al., 1994; Xiao et al., 2004), and two adopted a correlational design (Hooper et al., 2016; Suhr et al., 2010) to investigate the relationship between hydration status and cognitive functioning at the time of assessment. In healthy participants, 2 were intervention studies (one of which with a case-control design) (Suhr et al., 2004), and 1 an uncontrolled design (Ship & Fischer, 1997), inducing dehydration and/or re-hydration.

3.2 Study reporting strength

The mean reporting strength was 6.1 out of 10 and no publication was excluded on the basis of quality. Sampling was rated as acceptable for most studies, as most recruited participants from consecutive admissions to hospital either retrospectively or prospectively. However, the generalizability of most studies remains limited to the particular population considered, given that most studies included participants with a medical condition associated with dehydration (e.g. colonoscopy). Most sample sizes were appropriate and did not suffer from severe loss of data or refusal to participate. Study design was judged as appropriate for the purpose of most included studies. Retrospective designs were judged as appropriate only for those that assessed the financial costs of dehydration, while prospective designs were judged as better suited for studies assessing health outcomes of dehydration. Only two studies induced dehydration in healthy volunteers (Ship & Fischer, 1997; Suhr et al., 2004), and one adopted a suitable control group (Suhr et al., 2004). Most studies controlled for relevant confounding variables such as demographics, comorbidities and blood pressure. In terms of measurements, all studies adopted valid and reliable outcome measures, but measurements of dehydration were variable. Four studies (Khan et al., 2012; Wakefield et al., 2008; Warren et al., 1994; Xiao et al., 2004) used retrospectively reviewed clinical diagnoses to assess dehydration, which may have lead to bias due to misdiagnosis. All other studies adopted formal measurement of dehydration such as total body water, hematocrit, hemoglobin, plasma or serum sodium, BUN:creatinine ratio and serum osmolarity, and most used a combination of more than three. However, only one study adopted a combination of laboratory tests and clinical indicators of dehydration (e.g. dry tongue and lax skin) (Seymour et al., 1980).

3.3 Outcome of dehydration

Table 3 shows the outcomes of the 18 included studies. The outcome variables can be clustered into three groups: 1) general health outcomes, 2) costs of healthcare, 3) cognitive outcomes.

Table 3. Prevalence of dehydration, measurements and findings of the included studies

Study – first author, reference, location	Prevalence of Dehydration	Measurements		Main findings [a]
		Dehydration	Outcome	
Dehydration				
Ackland, 2008 (UK)	N/A	Lab tests (direct measure; pre-surgery and 3 days after surgery) - total body water a) % weight change; b) absolute bioimpedance change; c) percent calculated total body water change. Measured via single frequency 50 kHz leg–leg bioelectrical	Cognitive Outcome. Neuropsychological assessment: a) attention and executive functions (Trail Making Tests, TMT, A and B). b) memory/verbal learning (Rey Auditory Verbal Learning Test, RAVLT).	No difference in neuropsychological functioning before and after dehydration was caused by bowel preparation in the colonoscopy group (p=0.52), nor between groups (p=0.36).

		impedance analysis. Additional measures: hematocrit, hemoglobin, plasma Na and K, BUN:creatinine		
Chan, 2018 (China)	21.8%	Lab tests (from clinical records): BUN / Cr ratio > 25. Measurement at admission.	General Health Outcome. Mortality (30 day); postoperative complications during the first three post-operative days: clinical records	30 day mortality was greater for the dehydrated group (8.5%) than the euhydrated group (1.8%; chi-square test, p = .021) A greater proportion of dehydrated patients (61.7%) had more than one complication than euhydrated patients (43.8%; chi-square test, p = .030); respiratory, gastrointestinal & haematological complications particulary affected.
El-Sharkawy, 2015 (UK)	37% [b]	Lab test (from clinical records): serum osmolarity > 300mOsmol/kg.	General Health Outcome. Mortality (30-day in hospital)	More dehydrated participants among those who died in hospital (7% of participants died, of which 79% were dehydrated, p=0.001); Higher 30-days in-hospital mortality among dehydrated (16%) than euhydrated patients (4%, p=0.01).

		Measurement at baseline and 48h after admission. Additional measures: serum Na and K, BUN:creatinine, GFR	Costs of Healthcare. LOS: clinical records	Greater risk of mortality for dehydrated patients after controlling for age, gender, co-morbidity, National Early Warning Score (NEWS), frailty and nutritional status. No difference in median LOS in dehydrated (5 days) vs euhydrated (4, p=0.73)
Hooper, 2016 (UK)	20%	Lab tests – direct measurement: Serum osmolarity > 300 mOsm/kg. Measurement at baseline.	Cognitive Outcome Cognitive impairment: Mini-Mental State Examination (MMSE)	A negative relationship between MMSE and hydration status (risk factors included - poor renal function indicated by eGFR, diabetic medication use, and not taking potassium-sparing diuretics): coefficient (95% CI) = −0.37 (−0.56 to −0.18), $p < .001$. Using categorical DH scores, comparable multivariate logistic regression models revealed associations with MMSE subtest scores: Inability to draw two intersecting pentagons was associated with 74% greater odds of current dehydration, $p = .004$.
Johnson, 2015 (Sweden)	15.3% [b]	Lab tests – direct measurement a) renal conservation of water measured	General Health Outcome. Mortality (30, 90-day, 1 year):	30-day mortality: Higher for high vs low FRI (21% vs. 8%; p=0.03). Odds ratio (OR) of death in high FRI was 3.1 (95% CI:1.2–7.8). Positive linear relationship between mortality and urinary Na.

		through a composite fluid retention index (FRI) - urine color, specific gravity of 1.020 or higher, and urine osmolality >= 600 mOsmol/kg; b) urinary Na concentration	clinical records	Mortality higher for low urinary Na+high FRI (30%, n=10) vs very low urinary Na but low FRI (30 mmol/L; 20%, n=30, p=0.03) or normal urinary Na+low FRI (6%, p=0.001). Multivariate logistic regression analysis: high FRI (*p*0.044) and low urinary Na (*p*0.01) were independent predictors of death. None of the comorbidities was associated with mortality. <u>90-day mortality:</u> Higher only in very low urinary Na (47%) compared to 19% for the others (*p*0.003). None of the comorbidities was alone associated with mortality. <u>12-months mortality:</u> No difference
Khan, 2012 (UK)	N/A	ICD diagnosis - clinical records	General Health Outcome. Re-admission rates, mortality (1-year): clinical records	DH was the second most common cause of readmission (in 18.2% of patients) after pneumonia; the re-admitted group had a higher mortality rate at one year (41.8% vs 18.7%, $p < 0.001$). However, logistic regression did not identify DH as a predictor of re-admission.
McCrow, 2016 (Australia)	29% at admission, 21% at discharge	Either lab test – serum osmolarity ≥295 mmol/L – or clinical	General Health Outcome. Frailty: Clinical Frailty Scale	<u>Whole sample:</u> No difference in DH between cognitively impaired and intact patients, nor between frail and fit patients, both at admission and discharge <u>Within group differences:</u>

		assessment according to validated hospital procedures, both at baseline and discharge	Cognitive Outcome. Cognitive impairment: a) cognitive functioning - Rowland Universal Dementia Assessment Scale; b) delirium: Confusion Assessment Method	No differences in DH according to frailty status within the cognitively impaired group at admission (chi-square = 3.13, *df* = 1, *p* = 0.08) or discharge (chi-square = 0.06, *df* = 1, *p* = 0.81). Within the cognitively intact group, more frail patients were dehydrated (n=5) than fit patients (n=0) at admission (chi-square = 5, *df* = 1, *p* = 0.03). Most frail, cognitively intact, patients remained dehydrated at discharge (n=4), but the difference with the fit group at discharge only approached significance (chi-square = 0.621, *df* = 1, *P* = 0.06)
Mukand, 2003 (USA)	53.8% (patients with azotemia)	Prerenal azotemia: lab tests - BUN:creatinine of 20.	Costs of Healthcare. LOS and hospital outcome: clinical records	Azotemia vs no azotemia: All patients without azotemia returned home, vs 86% of those with azotemia. However, in logistic regression azotemia was not a predictor of hospital outcome (OR: 3.9, 95% CI: 0.4-39.6) Orthostasis vs no orthostasis 91% of patients without orthostasis returned home, vs 83% of those with orthostasis. However, in logistic regression, orthostasis was not a predictor of

				hospital outcome (OR: 1.9, 95% CI: 0.3-13.2) <u>Orthostasis+azotemia vs others (Two-way ANOVA):</u> Average LOS: 13.6 days for orthostasis+azotemia, 13.1 for orthostasis and no azotemia, 12.3 for azotemia and no orthostasis, and 7.2 days if neither condition was present. Significant main effect on LOS of both azotemia (F8.4, *P*.006) and orthostasis (F10.5, *P*.003) and significant interaction (F4.7, *P*.038).
Palmisano, 2014 (Italy)	N/A	Lab tests: creatinine, serum potassium, plasmatic osmolarity and Hematocrit	General Health Outcome. Clinical records: Number of temporary cardiac pacing and pacemaker implantations	Patients admitted in hot months showed increased DH compared to those admitted in cooler months. More patients underwent temporary cardiac pacing in summer than other seasons. No seasonal distribution in the number of patients undergoing pacemaker implantation. Patients admitted in the hot months had more frequently bradyarrhythmias secondary to reversible causes, and consequently were less likely to receive pacemaker. After excluding patients with bradyarrhythmias secondary to reversible causes, there was no significant difference in the seasonal distribution of patients undergoing temporary cardiac pacing (P =0.251).
Rodriguez, 2009 (USA)	N/A	Lab tests (from clinical records of emergency department): serum sodium, glucose,	General Health Outcome. Ischemic stroke and transient ischemic attack:	<u>Whole sample:</u> Mean plasma osmolality of patients (either ischemic stroke or transient ischemic attack) (293.4 ± 7.9 mOsm/kg) was higher than in healthy controls (291.5 ± 6.1 mOsm/kg, P = 0.0032). The difference in plasma osmolality between patients and healthy controls was

		and BUN. Plasma osmolality was calculated based onthe formula: [Sodium (mg/dl) 9 2 + Glucose (mg/dl)/18 + BUN (mg/dl)/2.8].	clinical records - Conventional clinical definitions. Ischemic stroke: acute neurological deficit lasting > 24 h; transient ischemic attack: when the deficit lasted < 24 h without evidence of primary intracerebral hemorrhage on neuroimaging studies	mainly due to higher BUN and glucose in the patient group. Over 65 years-old sub-group Significantly higher mean plasma osmolality in patients compared to healthy controls (295.6 ± 7.1 vs. 292.1 ± 6.3 mOsm/kg; P = 0.0005) Under 65 years-old sub-group No difference Multivariate linear regression analysis Confounders included high cholesterol and use of diuretics. In all patients and controls - no longer a significant difference, while this remained significant in patients over 65 years of age vs controls (295.4 vs. 292.3 mOsm/kg, difference 3.1, SE = 1.13, P = 0.006). Other analyses: Patients with diabetes mellitus had higher calculated plasma osmolality compared with those without (p = 0.0008 and 0.0078, respectively). Patients with cerebral ischemic events taking diuretics had significantly higher mean plasma osmolality levels compared with patients not taking diuretics (296.0 ± 8.0 vs. 292.4 ± 8.0 mOsm/kg, P = 0.0026), however there was no difference between those taking and not taking diuretics in the healthy controls.
Seymour, 1980 (Canada)	N/A	Lab tests: BUN:creatinine, Na, K, osmolarity,	Cognitive Outcome. Mental function:	No relationship between haematocrit or K and MSQ scores. BUN, Na, osmolality, and creatinine negatively correlated with MSQ scores, which could not be explained by age. No difference on any DH indicators between ACS and

		hematocrit. Clinical assessment (DH score): biochemical and clinical measurements collected at admission and one week later. i. Dry tongue and lax skin (1 point each). A fall in systolic hlood pressure of 10 mmHg or more on sitting or standing which disappears at 7 days (2 points). (Patients on known hypotensive drugs	history + 10 item mental status questionnaire (MSQ). 1. *Normal mental state (NMS):* a score of 8 points or more on admission. *2. Abnormal mental state (AMS):* a score of *1* points or less on admission. The abnormal group were further subdivided into: *a. Acute confusional states (ACS):* an initial	dementia sub-groups. MSQ scores on admission showed a significant negative correlation with the dehydration score ($0.005<p<0.01$, Table IV) and the BUN:creatinine *(p* = 0.05, Table IV, Fig. 2). In the ACS group the mean values of both the dehydration score and the BUN: creatinine were higher than in NMS patients. Overall conclusion is that a low mental score on admission is associated with a higher than average incidence of extra-cellular and plasma volume depletion but that the effect of age is minimal. A low mental score is particularly likely to be associated with dehydration/volume depletion when it occurs in the context of an acute confusional state.

		were scored as zero.) iii. A fall, over the week, in two or more of the following: haematocrit, 2.5% or more; BUN 10 mg/100 ml or more; osmolality 10 mOsm/kg or more (2 points). iv. A weight increase of more than 1.5 kg in a week in the absence of oedema (2 points). v. Pathological oedema scores *minus 2* points.	score of <7 with *either* a definite history of increasing confusion in the two weeks before admission, *or* a gain of *2* points or more on the MSQ between admission and the repeat assessment at one week. *b. Dementia* (persisting mental confusion): patients with initial mental scores of <7 who do not fall into category *a*.		

		Under this system, a maximum dehydration score is + 7 and a minimum score is — 2		
Ship, 1997 (USA)	N/A	Lab tests: hematocrit, hemoglobin, serum sodium, plasma protein, creatinine, serum osmolality, and urine osmolality	General Health Outcome. Parotid saliva was collected by placing a modified Carlson-Crittenden cup over the orifice of one parotid gland (Stenson's duct). If no unstimulated parotid flow was noted after 5 min, collection was discontinued and unstimulated	Unstimulated parotid salivary flow rates were approximately 90% lower than baseline after the 24-h DH period ($p < .001$). An increase in unstimulated flow occurred during and after rehydration but did not return to baseline values ($p < .001$) and remained 61.8% lower. Stimulated parotid flow rates decreased due to dehydration among older subjects (-27.9%; $p = .03$) but not for younger subjects (-6.62%; $p > .05$). Following rehydration, stimulated flow rates remained indistinguishable from baseline values. *Correlation data.* — No correlations between the level of hydration and salivary flow rates at baseline, 24 h, and 27 h. Change in salivary flow rate was not related to a change in hydration status. The percentage of baseline change in salivary flow rate was not related to a percentage of baseline change in hydration status.

			parotid flow rate was recorded as zero. "Unstimulated" saliva flow occurs when no exogenous or pharmacological stimulation is used. "Stimulated" saliva flow occurs when secretion is increased by gustatory stimuli.	
Suhr, 2004 (USA)	N/A	The Multiscan 5000 multifrequency bioelectrical impedance monitor used to measure total body water and the distribution of	Cognitive Outcome. a) Repeatable Battery for the Assessment of Neuropsychological Status	Bivariate correlations: Higher DH (%TBW/WT) was related to slower psychomotor processing speed, ($r = 0.49$, $p< 0.01$), and showed a trend for a relation to worse memory performance ($r= 0.34$, $p= 0.08$). Hierarchical regression analyses (confounds: demographic variables and systolic blood pressure). DH accounted for a significant amount of variance in performance above and beyond confounds for psychomotor processing speed

		extracellular compartment water (ECW) and intra-cellular compartment water (ICW). A regression formula was used to to estimate total body water from bioelectrical impedance data. Percent total body water by weight (%TBW/WT) used as final indicator of DH, as it allowed to control for body mass as a contributor to hydration status.	(RBANS): list learning and recall, story memory, copy and recall of a complex drawing, spatial judgments about the orientation of lines, object naming, word fluency, attention, and psychomotor processing speed b) Grooved peg-board test (GPT): bilateral manual dexterity. c) Trailmaking test (TMT): visual processing speed	($R^2 = 0.20$, $F = 7.91$, $p < 0.01$.) and memory ($R^2 = 0.17$, $F = 5.41$, $p < 0.05$)

			and cognitive flexibility.	
Suhr, 2010 (USA)	N/A	The Multiscan 5000 multifrequency bioelectrical impedance monitor used to measure total body water and the distribution of extracellular compartment water (ECW) and intra-cellular compartment water (ICW). A regression formula was used to to estimate total body water from bioelectrical impedance data. Percent total body	Cognitive Outcome. Cognition: Auditory Verbal Learning Test (AVLT) - Declarative memory, Working memory - Auditory Consonant Trigrams (ACT)	DH negatively correlated with verbal learning performance (r = .54, p = .01), and working memory performance (r = .47, p =.04). The relationship between DH and verbal learning, and DH and working memory, was mediated by diastolic blood pressure (DBP), while results for systolic blood pressure (SBP) did not reach significance. Increased DH was related to higher DBP, which in turn was related to poorer verbal learning and worse working memory; accounting for DBP significantly minimized the relation between DH and cognitive ability.

		water by weight (%TBW/WT) used as final indicator of DH, as it allowed to control for body mass as a contributor to hydration status.		
Wakefield, 2008 (USA)	149 out of 27242 (0.55% - three diagnoses combined); of these, 2.7% hypernatremic, 18.8% hyponatremic, 78.5% with volume depletion	Clinical records: ICD-9-CM codes 276.0, hyperosmolality or hypernatremia; 276.1, hypo-osmolality or hyponatremia; and 276.5, volume depletion. Patients with hypernatremia were excluded due to the	General Health Outcome. Mortality (30, 180-day): clinical records	No differences in 30 and 180-day mortality between hyponatremic patients (5.9% and 11.8% respectively) and controls (4.4% and 15.4%), nor between patients with volume depletion (1.4% and 16.7%) and controls

		small number.		
Warren, 1994 (USA)	6.7% (diagnosis of dehydration in any position); 1.4% (dehydration listed as the principal diagnosis).	Clinical records: ICD-9-CM code for volume depletion (276.5), as a principal (hospitalization *for* DH) or concomitant (hospitalization *with* DH) diagnosis, regardless of sodium status, since in most cases sodium status was not reported.	General Health Outcome Mortality and costs Costs of Healthcare. Clinical records	30-day mortality for patients hospitalized with DH: - as one of the diagnoses: 18% - as the principal diagnosis: 17.4% (and 48% one year-mortality) Comparison of mortality rates by principal diagnosis for hospitalizations with and without a concomitant diagnosis of DH showed that, for each principal diagnosis, hospitalizations with DH involved significantly higher 30 day and one year-mortality, with the exception of 30 day-deaths for Gastroenteritis. Cost (DH as principal diagnosis): $446 million -total reimbursement to hospitals $2942 - median cost per hospitalization.
Weinberg, 1994 (USA)	N/A	Lab tests - BUN:Creatinine (abnormal >25) and serum Na (ab > 146) drawn within 24-48 hrs from onset of febrile episode	General Health Outcome. Clinical records: mortality	DH prevalence: higher rates of elevated BUN:Creatinine and serum Na in the febrile (23% and 25% respectively) than the control group (2.7% for both values; p<0.05 and <0.01 respectively). In patients with impaired oral intake there were elevated values on either measure in 82% of cases (9/11). No controls had impaired oral intake. Mortality: 6 deaths (14%) in the febrile group, 5 of which had lab data; 100% had either elevated BUN:Creatinine or Na and 80% had both.

Xiao, 2004 (USA)	31077 hospitalizations for DH in 1999 in 984 hospitals located in 24 states	Clinical records: ICD-9-CM code for volume depletion (276.5) as a principal diagnosis	Costs of Healthcare. LOS and costs: clinical records	DH as principal diagnosis Average LOS: 4.6 days (excluding LOS for patients who died in hospital). Average total charge for hospitalizations: $7442 (median: $5437) Average charge per day: $1628

Abbreviations: DH, dehydration; Plasma Na and K, plasma sodium and potassium concentration; BUN:creatinine, blood urea nitrogen/creatinine ratio; GFR, glomerular filtration rate; LOS, length of hosptal stay.

[a] Presence/absence of difference/association implies presence/absence of statistical significance set at a p value of less than 0.05 unless otherwise specified. P values are always reported where provided by the study.

[b] Prevalence after exclusion of unsuitable participants.

3.3.1 General health outcomes of dehydration

3.3.1.1 Mortality

Mortality rates were assessed in 7 studies (Chan et al., 2018; El-Sharkawy, Watson, et al., 2015; Johnson et al., 2015; Khan et al., 2012; Wakefield et al., 2008; Warren et al., 1994; Weinberg et al., 1994) all of which took place in a hospital. Four studies (n (range) = 180 - 256 participants) (Chan et al., 2018; El-Sharkawy, Watson, et al., 2015; Johnson et al., 2015; Wakefield et al., 2008) compared 30-day mortality rates between dehydrated and euhydrated patients: 30-day mortality rates ranged from 1.4% to 21% for dehydrated, and 1.8% to 8% for euhdrated patients, with statistically significant differences reported for three studies (Chan et al., 2018; El-Sharkawy, Watson, et al., 2015; Johnson et al., 2015). This finding was consistent regardless of the dehydration index used: serum osmolarity (El-Sharkawy, Watson, et al., 2015), fluid retention index (Johnson et al., 2015), urinary sodium (Johnson et al., 2015), and blood urea nitrogen / creatinine ratio (Chan et al., 2018). Furthermore, a random effects meta-analysis estimated that the risk of 30-day mortality for dehydrated patients to be over twice that of euhydrated patients - average risk ratio, RR = 2.54 (95% CI [1.23, 5.254], p = .011), with small heterogeneity in study outcome (I^2 = 37.7%). Two studies examined 1-year mortality rates: one study found no increase in dehydrated patients (Johnson et al., 2015), while the other found that differences in mortality associated with dehydration remained increased at 1 year (Warren et al., 1994).

Two studies did not directly compare mortality rates. One examined the most common cause of re-admission in dehydrated and euhydrated patients, reporting that dehydration was the second most common cause of readmission (in 18.2% of patients) after pneumonia, and that readmitted patients had significantly higher 1-year mortality rates than those who were discharged home (Khan et al., 2012). Another examined dehydration in patients who died during an acute febrile episode, reporting that 100% of the patients who died had indicators of dehdyration (either elevated BUN:creatinine ratio or serum sodium; 80% had both) (Weinberg et al., 1994).

3.3.1.2 Other health outcomes

Other health outcomes were: frailty, bradyarrhythmia, ischemic stroke or transient ischemic attack, salivary flow rates, and post-operative outcomes, all of which were found to be linked to hydration status.

Frailty is a state of health in which body systems lose their in-built reserves, resulting in risk of adverse physical and mental outcomes (British Geriatrics Society, 2014). A link between dehydration and frailty was reported in one study (n = 44 participants) (McCrow et al., 2016), but only in patients who were cognitively intact: of cognitively intact patients, those who were frail were dehydrated at admission when compared to cognitively intact patients without frailty.

Bradyarrhythmia describes a low heart rate (under 60 beats per minute (BPM) in adults), with BPM lower than 50 resulting in symptoms of fatigue, weakness and dizziness. One study (n = 79 participants) (Palmisano et al., 2014) found seasonal variations in hospital admissions for bradyarrhythmia that varied with dehdyration, both of which were more prevalent in warmer months. Older adults are more prone to both dehydration and heat stress (Kenny, Yardley, Brown, Sigal, & Jay, 2010), putting them at greater risk of health conditions in the warmer months.

A transient ischemic attack occurs when blood flow to part of the brain is reduced and an ischemic stroke occurs when their blockage is more permanent. One study (n = 428 patients) (Rodriguez et al., 2009) reported that dehydration was increased in patients with ischemic stroke or transient ischemic attack compared to controls, and that this was restricted to those older than 65 years, suggesting that dehydration may be a particular risk for ischemic attacks in older adults.

Saliva has antifungal, antiviral and antibacterial properties, and is essential for oral health, with salivary flow disruption linked to problems with speech, mastication, swallowing, unpleasant breath and changes in taste. One study (n = 24, 12 older adults) (Ship & Fischer, 1997), reported that salivary flow rates decreased with dehydration, which did not completely recover with rehydration.

Finally, hydration status might be hypothesised to influence recovery from surgery. One study (n = 216 patients (Chan et al., 2018)) reported an association between dehydration on admission and the incidence of complications recorded in the first three post-operative days following orthopaedic surgery. The type of complications that were more likely to occur in those who were dehydrated included respiratory, gastrointestinal or haematological complications. Taken together, these studies suggest that negative health outcomes in older adults are linked to, and may be worsened, by dehydration.

3.3.2 Financial costs of healthcare

Four studies assessed the financial burden of dehydration related to hospitalisation, examining the monetary cost (Warren et al., 1994; Xiao et al., 2004) and length of stay.(El-Sharkawy, Watson, et al., 2015; Mukand et al., 2003; Xiao et al., 2004). These studies suggest that dehydration is highly costly for the health care systems and increases patients' length of hospital stay (LOS) and risk of readmission.

3.3.2.1 Monetary cost

Two USA-based studies estimated the monetary cost of hospitalizations for dehydration (n = 31077 and n = 286, respectively) (Warren et al., 1994; Xiao et al., 2004) by examining substantial numbers of hospital records and reporting the number of hospitalizations for dehydration as a principal diagnosis. The median costs per hospitalisation range between US$2942 (Warren et al., 1994) and US$5437(Xiao et al., 2004).

3.3.2.2 Increased length of stay

Three studies calculated LOS of patients hospitalized for dehydration as a principal or secondary diagnosis (n = 31,770), in the UK (n = 187) (El-Sharkawy, Watson, et al., 2015), and USA (n = 31077 and n = 39, repectively) (Mukand et al., 2003; Xiao et al., 2004). Two studies compared length of stay for patients hospitalised for dehydration with patients that were hospitalised for other reasons. One found that dehydration-related length of stay was longer (12.3 days compared to 7.2 days) (Mukand et al., 2003) and one found that it was not significantly longer (5 days compared to 4 days) (El-Sharkawy, Watson, et al., 2015). However, in the former case, length of stay was increased for those with prerenal azotemia (a change in blood flow to the kidneys) compared to those without (12.3 days compared to 7.2 days), where the presence of prerenal azotemia was used as a proxy for dehydration (Mukand et al., 2003). A further study reported the average length of stay for dehydrated patients only (4.6 days) (Xiao et al., 2004). An additional study reported that dehydration was the second most common diagnosis at readmission after hip fracture surgery (Khan et al., 2012).

3.3.3 Cognitive outcomes

Six studies investigated the relationship between dehydration and cognition in the elderly (Ackland et al., 2008; Hooper et al., 2016; McCrow et al., 2016; Seymour et al., 1980; Suhr et al., 2004, 2010). These are grouped into two categories: dementia and confusional state; and neurocognitive functioning.

3.3.3.1 Dementia and confusional state

Two hospital-based prospective cohort studies assessed the relationship between dehydration and dementia or confusional state in patients (n = 44 and n = 68, respectively), but the pattern of results was not consistent (McCrow et al., 2016; Seymour et al., 1980). One exploratory pilot study found no differences in hydration status between cognitively impaired and intact patients (McCrow et al., 2016), while another reported that mental function score was negatively correlated with bespoke dehydration scores (Seymour et al., 1980). This inconsistency could be a result of the use of different measures of dementia and confusion, dehydration, study size or reasons for admission.

One further observational study has assessed the relationship between hydration and cognitive status in a larger sample of older adults living in long-term residential care homes (n = 188) (Hooper et al., 2016). This revealed that dehydration was associated with level of cognitive impairment, even when other risk factors were controlled for statistically. However, as the authors acknowledge, it is impossible to infer direction of these relationships from the cross-sectional analysis reported: it is possible that cognitive impairment is a risk factor for dehydration, instead or as well as, being an outcome of dehydration.

3.3.3.2 Neurocognitive functioning

Three studies examined the association between dehydration and cognitive performance (n=101), one based in hospital (n = 52) (Ackland et al., 2008) and two in the community (n = 28 and n = 21) (Suhr et al., 2004, 2010). These suggest that there is some indication that older adults' memory is negatively affected by dehydration. One study reported correlations between dehydration and poor working memory (Suhr et al., 2010). A second examined group differences between older adults with dehydration induced by fluid restriction and euhydrated older adults, and reported memory differences that approached statistical significance (Suhr et al., 2004). However, in a hospital-based sample, no differences in verbal memory were observed in dehydrated older adults (Ackland et al., 2008). The measures used to assess memory were different in each study; effects of dehydration were observed on the Auditory Verbal Learning Test (Strauss, Sherman, & Spreen, 2006) (AVLT) (Suhr et al., 2010), the Repeatable Battery for the Assessment of Neuropsychological Status (Randolph, 1998) (RBANS) (Suhr et al., 2004), but not the Rey Auditory Learning Test (Rey, 1964) (RAVLT) (hospital sample) (Ackland et al., 2008). In addition to effects on memory, processing speed was impeded in dehydrated older adults in the community (Suhr et al., 2004), but not impaired in a hospital-based sample (Ackland et al., 2008); both studies used the Trail Making Tests A and B, with one using a composite including additional scores (Suhr et al., 2004). Two studies have suggested a role of increased blood pressure (hypertension) in the effect of dehydration on memory (Suhr et al., 2004, 2010).

4 Discussion

Our review suggests that dehydration in older adults is associated with significant detrimental effects to health, including increased mortality in hospitalized patients and increased likelihood of re-admission. These factors, amongst others, lead dehydration in older adults to contribute significantly to increased healthcare costs in this group. There is some indication that dehydration in older adults negatively impacts on cognitive performance, in particular for community dwelling older adults, but the evidence base is limited.

4.1 Health Outcomes

Studies report that dehydration diagnosed on admission to hospital is associated with increased 30 day mortality in older adults, after controlling for appropriate covariates, in a range of health conditions, and regardless of the measure used to assess hydration status (El-Sharkawy, Watson, et al., 2015; Johnson et al., 2015; Wakefield et al., 2008; Warren et al., 1994). Our meta-analysis showed that the rate is over twice as high in those who are dehydrated, compared to euhydrated individuals (El-Sharkawy, Watson, et al., 2015; Johnson et al., 2015; Wakefield et al., 2008). Furthermore, dehydration was the second most common cause of readmission to hospital for older adults (Khan et al., 2012), may worsen the course of illness (Palmisano et al., 2014; Rodriguez et al., 2009) or recovery from surgery (Chan et al., 2018), and is linked to increased bradyarrythmias (Palmisano et al., 2014) and ischemic illness (Rodriguez et al., 2009). Dehydration was also linked to frailty (McCrow et al., 2016), which may be related to findings suggesting that frail older adults need more assistance to drink (Mentes & Wang, 2010). The direction of the relation between frailty and dehydration is unclear; it is possible that dehydration is an unrecognised risk factor for frailty, as well as frailty potentially contributing to dehydration. In either case, this merits future research beause older adults with frailty are at increased risk of adverse outcomes in both physical and mental wellbeing (British Geriatrics Society, 2014).

4.2 Costs associated with dehydration

Given that dehydration is associated with poorer health, and that poorer health is linked to increased medical treatment, it is not surprising that the consensus is that dehydration in older adults is costly for health systems (Warren et al., 1994; Xiao et al., 2004). While one might expect poorer health to result in longer, and more costly, hospital stays, there was not a consensus on this (El-Sharkawy, Watson, et al., 2015; Mukand et al., 2003). While dehydration can be the sole cause of hospital admission, it can also be associated with one or many cormobities, such as diabetes, gastroenteritis, sepsis, urinary tract infections, or respiratory illness (Warren et al., 1994), all of which will contribute to the course and consequence of illness. One study in the USA in 1991 found that nearly five times as many hospital admissions for older adults included dehydration as a cormobidity (6.7%) than those for which it was the principal reason for admission (1.4%) (Warren et al., 1994). Measures to reduce dehydration in older adults may help reduce the associated burden on healthcare finances. For example, the incidence of urinary tract infections (UTIs) showed substantial reductions when a structured drink round was introducted that offered care home residents a drink seven times each day; UTIs requiring antibiotics reduced by 58% and associated hospital admissions reduced by 36% (Lean, Nawaz, Jawad, & Vincent, 2019). Reducing the health care burden by implementing similar interventions may be a fruitful avenue for future research.

4.3 Cognitive function

Few studies have assessed the effect of dehydration in older adults on cognitive performance. Three studies examined the link between dehydration and cognition, using a variety of cognitive tests that assess a range of cognitive processes (Ackland et al., 2008; Suhr et al., 2004, 2010). Two studies in the community showed that dehydration was linked to poorer memory performance (Suhr et al., 2004, 2010). This is is consistent with the literature in younger adults (Bar-David, Urkin, & Kozminsky, 2005; Fadda et al., 2012; Gopinathan et al., 1988). However, no memory detriment was found in a hospital based study that examined dehdyration induced by medication to clear the bowel in preparation for colonoscopy

(Ackland et al., 2008). However, differences in the selection process for the comparison groups in this study may have affected the results; the euhydrated comparison group were those who were suitable for sigmoidoscopy, while the dehydrated group were those selected for colonscopy.

There were inconsistent findings in studies that examined links between dehydration and dementia and/or confusional state (Hooper et al., 2016; McCrow et al., 2016; Seymour et al., 1980). In total, four studies showed links between dehydration and poor memory or increased dementia and/or confusional state, while two studies did not show such a relationship. The number of studies is limited, and the heterogeneity of cognitive functions tested and assessment methods adopted make it difficult to synthesise results. Therefore, we suggest that there is some indication that older adults's cognitive performance is negatively affected by dehydration particularly in the community, but the evidence is limited and more research is needed.

It is perhaps surprising that there is not a larger body of evidence on the effect of dehydration on cognition in older adults, as there is evidence that hydration status impacts on cognition in adults and children (Benton et al., 2016; Benton & Young, 2015), with negative impacts theoretically likely in older adults too (Benton, 2011). Some authors suggest that dehydration in older adults may exacerbate age-related changes in cogntive function (Maughan, 2003). However, these proposed links have yet to be assessed by large randomised controlled trials. Increasing the amount of fluid consumed might reverse negative effects of dehydration on cognition. Drinking water has been shown to improve performance in children (Benton & Burgess, 2009; Booth, Taylor, & Edmonds, 2012; Edmonds & Burford, 2009; Edmonds et al., 2017; Edmonds & Jeffes, 2009; Fadda et al., 2012), and adults (Benton et al., 2016;

Edmonds, Crombie, Ballieux, Gardner, & Dawkins, 2013; Edmonds, Crombie, & Gardner, 2013a, 2013b), even where there is only minimal dehydration (loss of <1% body mass) (Benton et al., 2016).

Age related changes in vascular function may be the mechanism by which dehydration affects cognitive performance in older adults (Suhr et al., 2004, 2010). While dehydration has been linked to high blood pressure (Watso & Farquhar, 2002) and changes in hydration status are associated with cardiovasular function (Patterson, VanderKaay, Shanholtzer, & Patterson, 2008; Rochette & Patterson, 2005), hypertension and poorly controlled high blood pressure have well-established negative effects on cognition in older adults (Waldstein, Brown, Maier, & Katzel, 2005). Furthermore, drinking additional fluid has also been shown to influence vascular functioning (Patterson et al., 2008; Rochette & Patterson, 2005). Thus, examining a possible mediating role of age-related changes in the vascular system in the effect of dehydration on cognition, or whether poorly controlled hypertension is a potential risk factor for negative effects of dehydration, should be considered by future research. Increasing fluid intake in older adults could be a promising intervention for both age-related cognitive impairments and vascular function associated with dehydration. Maintaining optimal cognitive function is an important component of sustaining independent living, and thus, potential effects on cognition and the mechanism involved should be the focus of future research. Intervention studies are required to improve our understanding of the effect of dehydration on cognitive performance in older adults.

4.4 Limitations and directions for future research

One limitation of this review is that we were only able to conduct meta-analyses for the 30 day mortality data and not for the other outcome measures, because these were not sufficiently consistent to be combined. In addition, there was a limited number of studies included and in this age group there are likely to be multiple comorbidities that could potentially confound the results. It is also noted that not all studies use the same measures and thus it is difficult to make cross study comparisons. For example, in the assessment of cognitive function, many different tests were used, and even when the same cognitive process was assessed (memory), different types of memory tests were employed.

There are limitations in study design in those studies included in the review, which may limit the interpretative power. Many of the studies are descriptive, or correlational rather than intervention studies. The generalizability of most included studies may remain limited to the particular population considered, given that they frequently included participants with a particular condition associated with dehydration (e.g. participants scheduled for colonoscopy). There is a clear need for prospective studies, and those that try to ameliorate the effect of dehydration in an experimental manner.

A further issue in the dehydration research area more generally is related to the measurement of hydration status. Commonly used clinical assessments of dehydration in older adults, such as feelings of thirst, a dry mouth and skin turgor, are not consistently accurate when diagnosing dehydration (Hooper, Abdelhamid, et al., 2015). Furthermore, there is an absence of agreed thresholds indicating that dehydration has occurred (Armstrong, 2012; Benton et al., 2015), and currently used measures may not be appropriate in all populations (Armstrong, 2012). The use of different measures and diagnostic criteria may impact on the reported prevalence of dehydration across studies. To mitigate difficulties in assessing and defining dehydration, many studies employ more than one marker. This is why, in our assessment of reporting strength, we gave a higher rating to studies that included more than one assessment of hydration status, in line with suggestions that a single marker is not sufficient (Armstrong, 2012) or that two or more are optimal (Kolasa, Lackey, & Grandjean, 2009). However, whichever measure of hydration is chosen, one off measurements could be described as 'simply "snapshots" of a complex, dynamic fluid matrix' (Kolasa et al., 2009). It may be more appropriate to use dehdyration measurement to examine change in hydration status over time, rather than to provide an accurate picture of an individual's hydration status at a given moment. Observations of individual differences in habitual fluid intake and predisposition to dehydration (Benton & Young, 2015) support the use of a dynamic measure of hydration status. However, unless a standard measure of hydration status and agreed diagnostic criteria are used consistently, caution must employed when interpreting and comparing findings across studies.

One avenue for future research should be to consider interventions aimed at reducing dehydration in older adults. Many older adults do not consume sufficient fluids, for example, one study in UK care homes found that, of 188 residents, 20% were dehydrated and a further 28% were in a state of impending dehdyration (Hooper et al., 2016). Underlying reasons include a weakening of the sensation of thirst (Hooper et al., 2016), that care home residents need help with drinking and need to wait for staff availability to provide drinks (Godfrey, Cloete, Dymond, & Long, 2012), and that some choose not to drink because of a fear of incontinence and needing to visit the toilet more frequently (Godfrey et al., 2012). Community dwelling older adults also consume insufficient drinks. For example, one study reported that 54% of older adults surveyed drank less than six glasses of fluid in a day (Picetti et al., 2017). Recently there has been more public awareness of the prevalence of dehydration in older adults (Knapton, 2015; Lawrence, 2011; Moody & Bennett, 2015), particularly those in care homes – awareness of this issue is likely to lead to interventions to help to ameliorate the situation (Hooper, Whitelock, & Bunn, 2015), such as the structured drinking intervention discussed above that reduced the severity of UTIs in care home residents (Lean et al., 2019). However, the challenge of increasing drinking in community dwelling older adults remains. For those older adults with access to smart phones, software applications ("apps") with reminders to drink and/or drink tracking might help; such apps are frequently used for dietary interventions (Coughlin et al., 2016) and increasing physical activity (Paul et al., 2017). However, challenges remain, with health related apps used by a small proportion of older adults compared to younger adults; a national survey in Germany found that 17% of their sample used health apps (Rasche et al., 2018), compared to 36% in a survey of younger American adults (Bhuyan et al., 2016). Barriers to app use in older adults, which include lack of trust, poor usability and lack of self-confidence, can be addressed by good app design (Wildenbos, Jaspers, Schijven, & Dusseljee-Peute, 2019) and this could be a focus of future work.

4.5 Conclusion

The present systematic review found significant negative effects of dehydration on health, the cost of healthcare and impairments in cognitive performance in older adults in the community. We can be most confident in the data from our meta-analysis, which found that 30 day mortality rates were over twice as high in dehdyrated compared to eudhydrated older hospitalised adults. Future work should evaluate ways of increasing hydration in dehydrated older adults, for example, by structured drinking rounds in care homes and hospital settings and mobile phone applications in community living older adults.

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Figure 1

PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart: Identification, screening, eligibility and inclusion of data sources.