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Is numeracy a barrier to glycaemic control in Type 1 diabetes mellitus? A synthesis of current literature

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Aims: Healthcare professionals rely on patients' health literacy and numeracy when providing education to enable self-management of diabetes. We review existing evidence for the impact of health literacy and numeracy on self-care processes in adults with Type 1 diabetes mellitus (T1DM).
Methods: A systematic review and narrative synthesis was performed. Four electronic databases were searched from inception to October 2015. Inclusion criteria included at least 70% adults (>17 years old) T1DM population, measurement of health literacy or numeracy with validated score and measure of self-care.
Results: A total of 972 articles were identified. Three articles met the inclusion criteria. There was heterogeneity of the studies although all studies used glycaemic control as the primary outcome. Six themes were identified, in particular, the association between numeracy and glycaemic control ($p = 0.004$, $p = 0.066$) in T1DM. No association was seen with health literacy.
Conclusions: Low numeracy appears to be associated with poorer glycaemic control in adults with T1DM, likely reflecting the skills needed for conventional insulin dose adjustment in T1DM. This review calls for more work to investigate this association further, aid identification and produce strategies to overcome low numeracy.

Key words: Health literacy, Numeracy, Type 1 diabetes mellitus, Self-care, Education, Dose adjustment, Insulin therapy, Insulin-dependent diabetes

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Self-efficacy is an important psychological construct associated with improved self-care abilities in chronic conditions, such as asthma and diabetes.[1] It can be defined as the person's confidence in their ability to perform certain behaviours.[2] Environmental and personal factors affect self-care abilities. Healthcare professionals rely on adequate literacy levels in their patients by providing written information and printed resources to transfer knowledge about diabetes and self-care.

Functional health literacy describes the ability to function in the healthcare environment. People with adequate health literacy skills are able to build on the information gained from their healthcare professional using the internet, where there are multiple blogs, forums and information sites with average reading age of 14 years.[3] However, the mean national reading age in UK adults is only 9 years and 25% of US citizens are functionally illiterate.[4,5] Illiteracy excludes individuals from improving their own health literacy and self-efficacy. Low health literacy has been linked with reduced diabetes knowledge and understanding of diabetes self-management, as well as adverse clinical outcomes, such as retinopathy.[6–9]

Numeracy (ability to use numbers in daily life) is a subskill of literacy[10] that is particularly central to many aspects of diabetes self-management. Health-related numeracy, like health literacy, requires additional skills to function in the healthcare system, such as interpreting risk, multi-step operations and identifying appropriate use of skill mix.[11] Effective intensive insulin therapy to manage Type 1 diabetes (T1DM) involves a multi-step numerical process.[10] First step is measuring and interpreting plasma glucose results then calculating the carbohydrate content of a meal. Last step is calculating insulin dosage, which relies on the first two tasks plus consideration of insulin ratios and correction doses. This complex numerical task involves several skills, including division, converting units and multiplication of decimals that only 40% of people are able to do.[11] The analysis of the information provided to people living with T1DM shows the content of an insulin dose adjustment task to be equivalent to level 2 –3 numeracy skill, the equivalent to higher level high school.[10] T1DM affects a cross-section of society.[12,13] Therefore, some people possess the skill mix necessary to digest written and numerical information, and make informed decisions about their daily self-care, while others lack the skills and struggle with these daily diabetes self-care decisions. This prevents them fully benefiting from advances made in healthcare.[10,14]

Clinically, there may be clues as to someone's numerical ability. For example, people with lower levels of numeracy leave school at an earlier age and have a higher level of unemployment.[15] However, educational attainment and general literacy are insufficient measures

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of health literacy or numeracy and validated scores are needed.[16] There is no current gold standard and nine health literacy and three numeracy scores have been identified.[17] The short Test Of Functional Health Literacy in Adults (sTOFHLA) and Rapid Estimate of Adult Literacy in Medicine (REALM) are most commonly used, having been validated in different languages and different patient groups, including people with diabetes. One diabetes-specific literacy and numeracy score exists.[18]

Despite the increasing interest in health literacy and numeracy and their influence on self-care of chronic conditions, there is little evidence for their impact in T1DM. T1DM is the exemplar of chronic conditions, requiring high-level numerical skills with easily measurable surrogate end points for self-care ability.

Rationale for the research question and method

A systematic review was conducted in order to review the evidence for the effect of health literacy and numeracy on self-care processes and to explore associated aspects of their impact on people with diabetes.[19] The review also sought to consider potential areas for supportive intervention to address the problem. Given the broad range of the review, a narrative synthesis was used to organise the extracted data into exploratory themes reflecting these objectives.[20] The synthesis seeks to identify themes within the literature that are encompassed within a developed narrative. Thematic consideration of the relationships between the relevant data allows the findings to be interpreted appropriate to the research question.

A population, intervention, control, outcome approach was used.[21] The population studied was adults (18 years or older) with T1DM. Studies with children were excluded, as they are unlikely to be self-caring and have not yet completed their education, so are expected to have a lower level of numeracy. Their carers or parents were also excluded, as the question concerns self-management and not management by another. Where the population was mixed (T1DM and T2DM or children and adults), the study was included if more than 70% participants met the inclusion criteria, or results could be extrapolated for this group. Studies with fewer than 20 people with T1DM were excluded.

The level of numeracy or health literacy (adequate versus inadequate) was the intervention studied. Only validated scores were included, while the assessment of educational attainment or profession was excluded as their association with numeracy is unclear.[22] Additionally, educational standards vary globally making it difficult to compare educational attainment across studies. Educational attainment is often based on graduation from a compulsory education system into voluntary. For example, compulsory schooling ends at age 16 in the UK with a General Certificate of Secondary Education (GCSE) examination.[23] In the USA ninth grade, which marks this transition, falls between 14 and 15 years old.

The outcome assessed self-care, for example, attendance at clinic, vaccination rate, glycaemic control or daily foot check. Glycated haemoglobin (HbA1c), a surrogate marker for glycaemic control, is not normally distributed so is often dealt with using a lognormal calculation, with median with interquartile ranges reported. Where necessary the Hozo formula was used to convert median and range into mean with standard deviation to enable comparison.[24]

There is a complex relationship between education, diabetes knowledge and self-care. Lower health literacy is linked to lower diabetes knowledge and reduced self-efficacy.[25] Diabetes education increases knowledge; however, health literacy may underpin the value of this education for individuals with low health literacy. Therefore, to enable exploration of the direct relationship between health literacy and self-care, diabetes knowledge was not included as either a measure of health literacy or an outcome.

Methods

The search criteria were produced in an iterative manner. Initial searches, based on previous Cochrane Collaborative search terms, identified articles from which keywords were identified and included in future searches, until the search was felt to be comprehensive[26] (Table 1). The search was limited to English language articles. The protocol was registered on the PROSPERO International prospective register of systematic reviews (ID CRD42015014278).

Two researchers (P.G.M. and S.M.H.) independently searched four databases from inception to October 2015; Medical Literature Analysis and Retrieval System Online (MEDLINE), PsycINFO, Excerpta Medica dataBASE (EMBASE) and Health Management Information Consortium (HMIC). Articles that were not primary source were excluded. Conference papers were included and authors contacted to provide further information where possible.

All titles of articles were read; non-relevant articles and duplicates were removed. Remaining article abstracts were read and potentially relevant articles retrieved and reviewed in full. Those not meeting the inclusion criteria on reading the full article were discarded[27] (Figure 1). Any disagreements between the two reviewers were discussed with a third author (H.M.). All studies meeting the inclusion criteria were hand-searched for additional relevant articles. Authors of included studies and experts in the field were contacted to recommend further articles or provide information about ongoing work.[28]

Data were collected independently from each eligible study by two authors (S.M.H. and H.M.), using variables defined a priori (Table 2). Authors that had not clearly described their study population or did not present

Table 1 Example search terms used to identify relevant articles in databases.

EMBASE classic + EMBASE search 23 October 2015	
Search term	Result
Health literacy/	4127
Numeracy.mp	933
(health and literacy).mp	9953
'rapid estimate of health literacy'.mp	1
'test of functional health literacy'.mp	368
'Hebrew health literacy test'.mp	1
'newest vital signs'.mp	5
'short assessment of health literacy'.mp	15
'wide range achievement test'.mp	439
'nutritional literacy'.mp	8
'literacy assessment for diabetes'.mp	5
'single item numeracy screener'.mp	0
'demographic assessment'.mp	39
'brief estimate'.mp	8
'diabetes numeracy'.mp	19
'medical data interpretation'.mp	7
'subjective numeracy'.mp	41
'numeracy test'.mp	36
(diabet$ adj2 litera$).mp	482
(diabet$ adj2 numera$).mp	37
1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10 or 11 or 12 or 13 or 14 or 15 or 16 or 17 or 18 or 19 or 20	11 332
Exp insulin dependent diabetes mellitus	86 036
'insulin-depend$ diabet$' or 'insulin depend$ diabet$' or 'insulin depend$ diabet$'.mp	238 917
'type 1 diabet$' or 'type1 diabet$' or 'type-1 diabet$'.mp	44 888
'type I diabet$' or 'typeI diabet$' or 'type-I diabet$'	7964
Child adj2 diabet$.mp	742
Acidos$ adj2 diabet$.mp	1300
Labil$ adj2 diabet$.mp	203
Keto$ adj2 diabet$.mp	11 018
Juvenile$ adj2 diabet$.mp	5423
Autoimmune$ adj2 diabet$.mp	4409
(Auto and immune$) adj2 diabet$.mp	302
(Sudden and onset) adj2 diabet$.mp	194
22 or 23 or 24 or 25 or 26 or 27 or 28 or 29 or 30 or 31 or 32 or 33	260 979
21 and 34	446
Limit 35 to (human and English language and (adult 18–64 years or aged 65+ years)	210

separate results for participants meeting our inclusion criteria were contacted for additional information. Study bias was assessed at study level using a critical appraisal tool, with high -risk studies excluded.[29]

Authors used narrative synthesis to identify themes individually and then met to discuss these and their interpretation of the data, refining the themes to allow the research question to be addressed. Where possible, a scoring system was sought using the validation papers for each score to identify a universal equivalent score to enable comparison.[17] Where this was not possible, the scores were converted to equivalent educational attainment level.

Results

The initial search identified 972 studies, after reviewing titles and abstracts, 40 papers were thoroughly assessed leaving three peer-reviewed studies that met the inclusion criteria for review (Appendix). The included studies are summarised in Table 2.

Study designs

All three studies used English- speaking adults (18–65 years old) with at least 1 year of diagnosis from USA and UK. The USA- based studies recruited participants from across primary and specialist care, and included a mixed population of both T1DM and T2DM. The UK- based study recruited individuals with T1DM only from specialist care.

All three studies used a cross-sectional survey design, meaning that association, but not causation, can be interpreted. Response rates varied from 17 to 64% with sample sizes ranging from 112 to 398 participants (mean 234 participants). All study surveys collected demographic- and diabetes- specific measures, as well as formally assessing numeracy and/or literacy levels. One study used the UK Skills for Life assessment tool, a score used within the British education system but not validated for use in healthcare. The other studies used a diabetes- specific measure of numeracy and health literacy, the Diabetes Numeracy Test (DNT). Other measures, REALM and Wide Range Achievement Test (WRAT), were also used in one study. All studies used these scores to determine the influence of health literacy and numeracy on diabetes outcomes, using recent HbA1c (within 3–6 months of study). All of the studies used multivariate modelling to adjust for covariates, such as age, sex and type of diabetes.

The identification of only three studies and the use of different scoring systems between studies made narrative synthesis the optimal analytic tool.[30] Six main themes were highlighted:

- Measures of numeracy and health literacy.
- Numeracy and glycaemic control.
- Numeracy and diabetes type.
- Numeracy and self-care.
- Literacy and glycaemic control.
- The impact of socio-economic factors.

Measures of numeracy and health literacy

The use of different scoring systems has made direct comparison difficult. For example, the skills for life score was originally categorised according to Level 2 numeracy. Level 2 numeracy in the British education system is not equivalent to American ninth grade, as it is an above average achievement, achieved at an older age than in the USA system (16 years versus 14 years).[23] This inconsistency of scoring was dealt with by converting DNT scores into quartiles (G1–4), based on reported results of the entire study population. These quartiles were then compared with other validated scores in order to draw direct comparisons across the studies. Fourteen per cent of participants achieving greater than ninth grade numeracy on WRAT fell into G1–2 of DNT. Therefore, G1 DNT was considered equivalent to less than ninth grade numeracy and G3 was considered

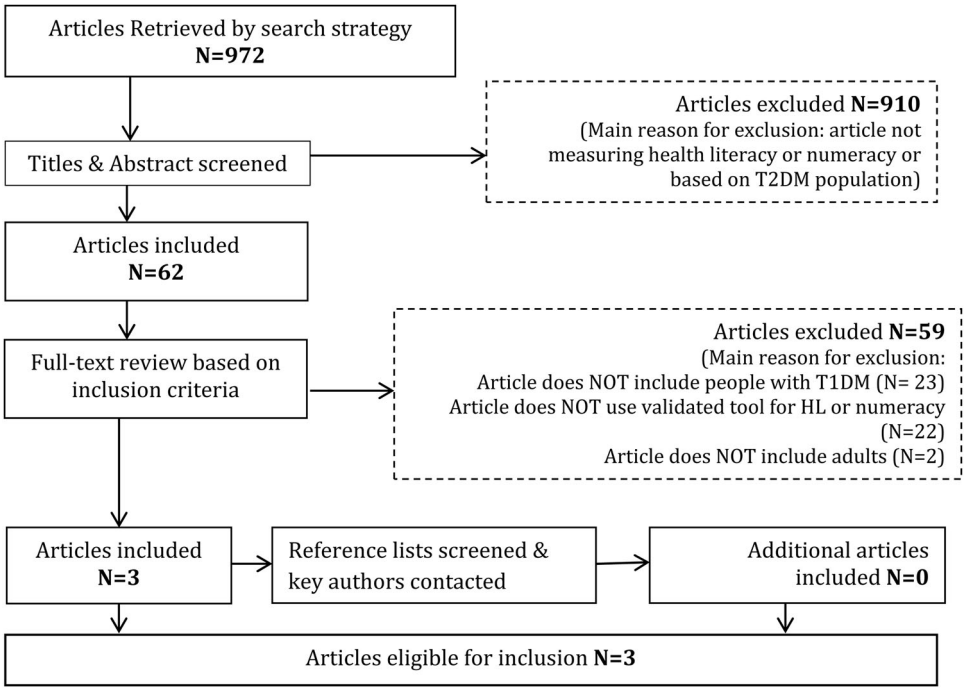

Figure 1 PRISMA flow diagram of the selection of studies.

Table 2 Selected characteristics of three studies included in this review.

Study	Population	Design and allocation	Numeracy and HL, biometric and demographic measures	Analysis and results
S. Marden *et al.* 'Poor numeracy skills are associated with glycaemic control in Type 1 diabetes' Diabetic Medicine 29, 662–669 (2012)	Adult (18–65 years) Type 1 attending secondary care clinic, UK; Sample population similar to clinic population	Cross-sectional survey using random number generator Stopped recruiting at 112 according to the sample calculator. 17% response rate	UK skills for life (SFL)/adult core curriculum (40 literacy, 25 numeracy measures), 1–2 h to complete; HbA1c within 3 months; Educational attainment; Index of Multiple Deprivation (IMD) score; Attendance at structured education	Categorised SFL score; Level 1 (L1) or Level 2 (L2) 75% <L2 literacy 47% <L2 numeracy; Mean HbA1c; not associated with literacy, but associated with numeracy after adjustment Parsimonious model found numeracy associated with HbA1c, age, age left school
S. Zaugg *et al.* 'Diabetes Numeracy and Blood Glucose Control: Association with Type of diabetes and source of care' Clinical Diabetes 32(4), 152–157, 2014	Mixed (T1&T2) adult population with >1 year diagnosis English speaking primary and secondary care, USA	Cross-sectional survey study 194 recruited according to the sample calculator. Not powered for T1. Recruited at clinic appointment. No mention of allocation or response rate.	Demographic data (supplemented by records); Disease duration and type; Most recent HbA1c; Care provider (primary and secondary care) DNT-15	Mean ANCOVA with post-hoc analysis adjusting for variables. Higher DNT associated with secondary care and educational attainment; DNT negative correlated with HbA1c for T1 group
K. Cavanaugh *et al.* 'Association of numeracy and diabetes control' Ann Int Med 2008; 148; 737–746	Mixed (T1&T2) adult (18–65 years) population with >1 year diagnosis English speaking primary and secondary care USA Excluded blind/partial sighted/ dementia $20 incentive	Cross-sectional study 615 identified; 398 completed; (64% response rate)	Demographics; Treatment Disease duration and type; HbA1c within last 6 months; BMI; Summary of diabetes self-care activities; Perceived diabetes self-management scale REALM WRAT-3 DNT Diabetes knowledge test	Median and IQR DNT percentage; Quartile of DNT; REALM and WRAT categorised to ninth grade; GLM log-HbA1c and DNT with adjustment; High DNT associated with greater perceived self-efficacy High DNT association with lower HbA1c (non-significant)

Information includes details of the study population, methods and design, outcomes measure, analysis and results, conclusion and limitations taken from the study authors and authors of this review. Health literacy (HL), Diabetes numeracy test (DNT), Skill for life (SFL), Glycated Haemoglobin (HbA1c), Structured education (SE), Type 1 diabetes (T1), Type 2 diabetes (T2), Primary care (first care), Secondary care (second care), Rapid estimate of adult literacy measure (REALM), Wide range achievement test (WRAT), Analysis of covariance (ANCOVA), Generalised linear model (GLM), Body mass index (BMI).

Table 3 Results of self-care outcomes according to health literacy or numeracy score extrapolated from all studies included in systematic review.

Study Author Score used Reported *p* -value	Group 1	Group 2	Group 3	Group 4
Marden et al. 2012 Diabetic Medicine 29(5); 662–9 Skills for life (numeracy) $p = 0.004$		Mean HbA1c 9.2 ± 1.7% (77 ± 18 mmol/mol) $n = 53$	Mean HbA1c 8.4 ± 1.2% (68 ± 13 mmol/mol) $n = 59$	
Zaugg et al. 2014 Clinical Diabetes 32(4); 152–7 DNT15	Mean HbA1c 9.45 ± 3.03% (79.8 ± 33.2 mmol/mol) $n = 4$	Mean HbA1c 8.39 ± 1.62% (68.2 ± 17.6 mmol/mol) $n = 15$	Mean HbA1c 8.13 ± 1.4% (65.4 ± 15.3 mmol/mol) $n = 25$	Mean HbA1c 7.6 ± 0.89% (59.6 ± 9.7 mmol/mol) $n = 15$
Cavanaugh et al. 2008 Annals of Internal Medicine 148; 737–46 DNT score $p = 0.066$	Median HbA1c 8.8% IQR 6.9–10.3% $n = 3$ Mean HbA1c 8.7 ± 1.0025% (71.6 ± 10.8 mmol/mol)	Median HbA1c 8.1% IQR 7.3–8.7% n = 6 Mean HbA1c 8.05 ± 0.453% (65 ± 4.4 mmol/mol)	Median HbA1c 7.5% IQR 7.1–9.1% n = 13 Mean HbA1c 7.8 ± 0.629% (61.7 ± 6.9 mmol/mol)	Median HbA1c 7.1% IQR 6.5–8.0% n = 33 Mean HbA1c 7.175 ± 0.375% (54.9 ± 4.1 mmol/mol)

p-values taken from primary source; statistical significance taken as $p < 0.05$. *Mean HbA1c* calculated from reported median.

equivalent to level 2 numeracy in the British education system. Therefore, the Skills for Life scores was tabulated either side of the DNT mean (G2–3) (Table 3).

Numeracy and glycaemic control

Numeracy and glycaemic control appear to be linked, with the strength of this relationship varying from clear statistical significance to simple trend.[31,32] Marden *et al.*[31] found a statistical difference in mean HbA1c values for participants above and below level 2 numeracy (68 ± 13 mmol/mol (8.4 ± 1.2%) versus 77 ± 18 mmol/mol (9.2 ± 1.7%) $p = 0.004$). This result is corroborated by Cavanaugh *et al.*,[11] who found a 10% decrease in DNT correlating to a 0.09% increase in HbA1c (95% CI 0.01–0.16%, $p = 0.027$).

Numeracy according to diabetes type

This review specifically wished to examine the effect of numeracy on glycaemic control in people with T1DM. However, the inclusion of two studies using mixed populations has allowed identification of the difference between individuals with T1DM compared with T2DM. Cavanaugh *et al.* reported a negative association between numeracy and glycaemic control in those with T1DM. Although clinically relevant, it was not statistically significant due to inadequate sample size. Zaugg *et al.* reported an interaction effect between the type of diabetes and the DNT15 score, finding a negative correlation between numeracy level and glycaemic control in T1DM, after adjusting for gender and level of education ($p = 0.043$).[32]

These findings suggest that sufficient numeracy is more important for those with T1DM. The study's authors remarked upon the greater level of numeracy required to achieve good glycaemic control in T1DM compared with T2DM, due to the numerical requirements (decimals, fractions, percentages and converting units of measure) associated with carbohydrate counting and administering the correct dose of insulin.[31,32] Higher numeracy levels were seen in those with T1DM compared with T2DM. However, no association between DNT score and insulin use was found within a mixed population.[11]

Numeracy and self-care

Only one study examined the effect of numeracy on other measures of self-care. In Cavanaugh *et al.*'s, mixed population higher numeracy was associated with higher levels of diabetes-specific knowledge ($p = 0.001$) and greater self-efficacy (9 –12.5%, $p = 0.003$).

Literacy and glycaemic control

The link between literacy and glycaemic control in T1DM is less convincing than that of numeracy. Only Marden *et al.* specifically examined this relationship, independent of numeracy, and found no significant variation in mean HbA1c between the two groups above and below level 2 literacy (8.6 ± 1.3% (70 ± 15 mmol/mol) compared with 8.8 ± 1.6% (73 ± 17 mmol/mol) ($p = 0.56$)). Moreover, Cavanaugh *et al.* report no association despite finding low literacy to be associated with lower DNT scores ($p = 0.001$) and the afore mentioned effect of numeracy on glycaemic control.

The impact of socio-economic factors

Recognition of the complex interplay of demographics and socio-economic factors with glycaemic control resulted in all the studies considering such influences within their study design; either by controlling for covariates to reliably determine the true relationship between glycaemic control and health literacy and numeracy levels or by exploring how the factors themselves relate. While all of the studies considered age, gender and educational attainment, Cavanaugh *et al.* and Marden *et al.* explored socio-economic status.

Numeracy appears to be independently associated with glycaemic control after controlling for socioeconomic factors. Linear regression modelling of glycaemic control with numeracy and health literacy when adjusted for age, gender, socio-economic deprivation (based on postcode), educational attainment and duration with diabetes showed that numeracy alone had a significant association (standardised coefficient β −0.17 (−1.18 to −0.07) $p = 0.027$).[31] Despite Cavanaugh *et al.* using a mixed population, their regression analysis corroborates this, with modest association between HbA1c and DNT score, after adjusting for demographic and health factors.

Having found a correlation between numeracy and glycaemic control, Cavanaugh *et al.* explored characteristics associated with lower DNT scores. They found lower scores in individuals of older age, non-white ethnicity, lower educational attainment and lower socio-economic status.[11] Although older age was associated with lower numeracy levels, there appeared to be an inverse relationship with glycaemic control, both in a mixed population with HbA1c decreasing by 0.17% for every 5-year increase in age (CI 0.10% to 0.24%; $p = 0.001$) and in a T1DM- only population.[11,31]

Educational attainment appeared to influence glycaemic control, with those who left school at 18 achieving better glycaemic control than those that left at 16.[31] Zaugg *et al.*[32] did not report a link between glycaemic control and education, but found a correlation between the highest level of education completed and the DNT-15 scores ($p = 0.004$), after adjusting for gender, type of diabetes and age.

Discussion

Despite only identifying three eligible studies, six themes were identified via narrative synthesis. Specifically, higher numeracy levels were associated with greater glycaemic control in adults with T1DM. This may reflect the nature of skills required to achieve success with carbohydrate counting and insulin dose adjustment associated with complete insulin deficiency seen in T1DM. The lesser degrees of insulin deficiency seen in T2DM may mean less precision is needed to achieve glycaemic control, accounting for the weaker effect of numeracy in this group of individuals.

Alternatively, the regularity with which people with T1DM use skills for dose adjustment may mean that numeracy improves overtime. This is supported by mixed population studies finding a higher proportion of people with T1DM in the top quartile of numeracy score along with the increased self-efficacy and diabetes knowledge found in those with greater numeracy.[11,33] Cross-sectional study design means causality is uncertain, and can only be hypothesised at this stage.

In an era of increasingly collaborative patient-centred care, the ability to navigate the healthcare system, understand instructions and compute health choices are important skills for self-management. It is surprising that insufficient evidence to support the effect of health literacy exists, possibly due to inadequate number of studies. Previous studies have found a relationship between health literacy and glycaemic control, with a trend seen in T1DM.[22]

Michie *et al.*[34] hypothesise that behavioural change is due to the interaction between three components: capability, opportunity and motivation (COM-B model). Numeracy appears relevant to 'opportunity' referring to 'factors that lie outside the individual that make the behaviour possible', including physical, mental and social aspects of the individual's thought process. We suggest poor numeracy has a detrimental effect on the ability to achieve target glycaemic control. To effectively improve self-care in individuals with low numeracy, the COM-B framework suggests interventions using education, persuasion and incentivisation.[34]

The British 'Skills for Life' survey in 2003 found over half the nation had an average reading age of a 9-year-old.[5,35] Similarly, 25% of American adults are functionally illiterate.[4] Improving individual numeracy has become of increasing importance to national governments, with the British government announcing plans to raise the functional literacy and numeracy of the working population to 95% by 2020. The economic argument for investing in up-skilling the nation is strong, with 13% increase in earnings for those who attend a basic mathematics course. Additionally, the government could reduce public health spending, as those with low health literacy have more hospital admissions (31.5 versus 14.9%).[36]

Healthcare professionals offer an alternative strategy. The American Medical Association recommend further education and funding for current and future healthcare professionals to gain skills to appropriately communicate with patients with limited literacy.[4] Language choice and communication are fundamental to deploy persuasive and incentivising techniques during the consultation. Through continuous professional development, skills can be learned to enable more comprehensive communication with patients with low literacy, such as making their instructions more interactive and asking patients to do, write, say or show to prove understanding.[37] Fewer than 5% of healthcare professionals currently check their patients' understanding of their medical consultation.[38] However, the healthcare professional's knowledge of their patients' numeracy or literacy ability alone appears to be insufficient to improve self-care in diabetes, and tailored education is necessary.[39] A randomised controlled trial reports the use of diabetes educational materials and methods tailored to an individual's needs versus standard educational methods. Both groups saw an improvement in HbA1c, which was significantly greater in the group receiving tailored education (−1.5 versus −0.8%, $p = 0.005$) at 3 months, but no longer significant at 6 months (−1.05 versus −0.9%, $p = 1$).[40]

A third strategy absolves the need for individual numerical skills via use of technology, for example

insulin bolus calculators (either integrated with glucose metres or as smartphone applications), which automatically calculate appropriate insulin dose according to an algorithm and parameters defined by an individual's diabetes specialist.[41–44] These have been shown to improve adherence by overcoming some of the motivational components of good glycaemic control, such as fears of hypoglycaemia, but have not yet been trialled specifically in people with reduced numeracy.[45] These technologies need to be user- friendly, seamlessly communicating between glucometer and calculator with potential for digitalised carbohydrate portion estimation in the future. As poor numeracy is associated with reduced use of more complicated insulin pump functions such as dual wave boluses,[46] further work is needed to ensure health inequalities are not widened by inadvertently restricting technology use to the health literate.[47]

Demographics, such as educational attainment, employment status, age and ethnicity, could be considered as other factors associated with 'opportunity' and therefore impact on glycaemic control. These factors may also be clues to poor numeracy, but are insufficiently correlated to absolve the need for assessment.[4] The lack of gold standard assessment for numeracy has limited our review, as different numeracy and literacy tests were used, making cross referencing and comparison of studies difficult. Additionally, comparison was made between two different health systems: the USA insurance-based system has a greater number of adults with diabetes receiving diabetes education than the UK insurance-based system (57% in 2010 versus 5.3% 2014–2015).[48,49] Despite this, we found a relationship between numeracy and HbA1c, making these results generalizable to other populations.

Conclusion

Numeracy is associated with glycaemic control in people with T1DM, likely due to the degree of precision required in those with complete insulin deficiency. Further work is necessary to confirm this association, as well as define tools to appropriately identify those with lower numeracy. Interventions focusing on education, persuasion and incentivization need to be developed to enable those with low numeracy to achieve glycaemic targets.

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Appendix.

Reference	Included?	Inclusion Criteria	Contact with author
Anonymous (2008) Summaries for patients. Association of numeracy and diabetes control. Annals of internal medicine 148: I53	No	Unavailable	
Anonymous (2013) Singapore Health and Biomedical Congress, SHBC 2013. Annals of the Academy of Medicine Singapore Conference: Singapore Health and Biomedical Congress, SHBC 42	No	Not available in library or inter-library loan	
Abdulazeez MA, Busari AI, Yakubu S, Anigo KM, Idris HO, Salihu A (2013) Prevalence of hypertension and impaired renal function in diabetic patients attending Ahmadu Bello University Teaching Hospital (ABUTH), Shika, Zaria, Kaduna State, Nigeria. Journal of Medical Sciences (Faisalabad) 13: 346–352	No	No health literacy/numeracy measure 36% T1DM	
Arifulla M, John LJ, Sreedharan J, Muttappallymyalil J, Basha SA (2014) Patients' adherence to anti-diabetic medications in a Hospital at Ajman, UAE. Malaysian Journal of Medical Sciences 21: 44–49	No	T2DM	
Bahru Y, Abdulkadir J (1993) Assessment of diabetes education in the teaching hospital, Addis Ababa, Ethiopia. Diabetic Medicine 10: 870–873	No	No health literacy/numeracy measure	
Bains S, Osborn CY, Egede LE (2010) Demographic proxies predict diabetes self-care behaviors above and beyond health literacy. Journal of Investigative Medicine 58 (2): 386	No	T2DM - not specified in methods, but in discussion	
Barnard K, Parkin C, Young A, Ashraf M (2012) Use of an automated bolus calculator reduces fear of hypoglycemia and improves confidence in dosage accuracy in patients with type 1 diabetes mellitus treated with multiple daily insulin injections. Journal of Diabetes Science & Technology 6: 144–149	No	No health literacy/numeracy measure	

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Appendix. *Continued*

Reference	Included?	Inclusion Criteria	Contact with author
Baz L, Muller N, Beluchin E, et al. (2012) Differences in the quality of diabetes care caused by social inequalities disappear after treatment and education in a tertiary care centre. Diabetic medicine : a journal of the British Diabetic Association 29: 640–645	No	No health literacy/numeracy measure	
Beggan MP, Cregan D, Drury MI (1982) Assessment of the outcome of an educational programme of diabetes self-care. Diabetologia 23: 246–251	No	No health literacy/numeracy measure Children/adolescents	
Bella AF (1992) A prospective study of insulin-dependent diabetic Nigerian Africans. Journal of the National Medical Association 84: 126–128	No	No health literacy/numeracy measure	
Bergers J, Nijhuis F, Janssen M, van der Horst F (1999) Employment careers of young type I diabetic patients in The Netherlands. J Occup Environ Med 41: 1005–1010	No	No health literacy/numeracy measure	
Bernal H, Wooley S, Schensul JJ (1997) The challenge of using Likert-type scales with low-literate ethnic populations. Nursing research 46: 179–181	No	Feasibility/score design study No diabetes outcomes	
Beverly EA, Ganda OP, Ritholz MD, et al. (2012) Look who's (not) talking: diabetic patients' willingness to discuss self-care with physicians. Diabetes Care 35: 1466–1472	No	No health literacy/numeracy measure	
Bhargava A, Wartak SA, Friderici J, Rothberg MB (2014) The impact of Hispanic ethnicity on knowledge and behavior among patients with diabetes. The Diabetes educator 40: 336–343	No	No health literacy/numeracy measure Unclear if T2/T1	
Buysse HE, de Moor GJ, de Maeseneer J (2013) Introducing a telemonitoring platform for diabetic patients in primary care: will it increase the socio-digital divide? Primary care diabetes 7: 119–127	No	No health literacy/numeracy measure	
Campos-Barrera E, Duran-Perez EG, Almedavaldes P, Mehta R, Cuevas-Ramos D, Gomezperez FJ (2011) Impact of diabetes-related numeracy, diabetes self-care activities and depression on metabolic control in patients with type 1 diabetes mellitus. Diabetes 60	Yes	Conference abstract so insufficient detail	Email x2 to author 30/3/16 – no reply
Cavanaugh K, Huizinga MM, Wallston KA, et al. (2008) Association of numeracy and diabetes control. [Summary for patients in Ann Intern Med. 2008 May 20;148(10):I53; PMID: 18490670]. Annals of Internal Medicine 148: 737–746	Yes	T1DM & T2DM mixed	Communication with R. Rothmann to recommend further 24/2/15
Chaturvedi N, Stephenson JM, Fuller JH (1996) The relationship between socioeconomic status and diabetes control and complications in the EURODIAB IDDM Complications Study. Diabetes Care 19: 423–430	No	No health literacy/numeracy measure	
Erkkola M, Salmenhaara M, Kronberg-Kippila C, et al. (2010) Determinants of breast-feeding in a Finnish birth cohort. Public Health Nutr 13: 504–513	No	Risk of T1DM (not actually T1DM)	
Ford S, Mai F, Manson A, Rukin N, Dunne F (2000) Diabetes knowledge--are patients getting the message? Int J Clin Pract 54: 535–536	No	No measure of self-care Type of diabetes not specified	
Goldsmith D, Anis M, Dieguez Otero K, Hasan SA (2012) Influence of health literacy on diabetes mellitus outcomes. Journal of General Internal Medicine 27: S229	No	Conference abstract – mixed population, no further data re: proportions/ individual T1DM	No response to email. (29/2/15)
Ismail IS, Nazaimoon WM, Mohamad WB, et al. (2000) Sociodemographic determinants of glycaemic control in young diabetic patients in peninsular Malaysia. Diabetes Research & Clinical Practice 47: 57–69	No	No health literacy/numeracy measure T2DM	
Jabbar A, Contractor Z, Ebrahim MA, Mahmood K (2001) Standard of knowledge about their disease among patients with diabetes in Karachi, Pakistan. Jpma The Journal of the Pakistan Medical Association. 51: 216–218	No	T2DM	
Japiassu LM, Brito GNO, Castro SH, Gomes MB (2015) A comparison of the neurobehavioral profile of type 1 and type 2 diabetes patients. Diabetes 64: A231	No	No 2nd outcome	

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Appendix. *Continued*

Reference	Included?	Inclusion Criteria	Contact with author
Kiani J, Moghimbeigi A, Azizkhani H, Kosarifard S (2013) The prevalence and associated risk factors of peripheral diabetic neuropathy in Hamedan, Iran. Archives of Iranian Medicine 16: 17–19	No	No health literacy/numeracy measure	
Klupa T, Matejko B, Kiec-Wilk B, Malecki MT (2013) Factors affecting glycaemic control in adult type 1 diabetic patients treated with personal insulin pumps. Diabetologia 56: S443	No	No health literacy/numeracy measure	
Lui CW, Dower J, Donald M, Coll JR (2012) Patterns and determinants of complementary and alternative medicine practitioner use among adults with diabetes in Queensland, Australia. Evidence-based Complementary and Alternative Medicine	No	No health literacy/numeracy measure	
Marks GR (2002) Relationships between diabetes knowledge, beliefs, perceived health competence, personality, and diabetes-related outcomes in adults with type I diabetes. Dissertation Abstracts International: Section B: The Sciences and Engineering 62: 5971	No	Unable to get article from library	No response to email. No published results available with search of author.
Mancuso J (2010) Impact of health literacy and patient trust on glycemic control in an urban USA population. Nursing and Health Sciences 12: 94–104	No	3.9% T1DM	Contacted for further details but email box full
Marden S, Thomas PW, Sheppard ZA, Knott J, Lueddeke J, Kerr D (2012) Poor numeracy skills are associated with glycaemic control in Type1 diabetes. Diabetic Medicine 29: 662–669	Yes		Contacted D. Kerr for recommendation or new data (29/2/15)
Martinez-Huedo MA, Lopez de Andres A, Hernandez-Barrera V, Carrasco-Garrido P, Martinez Hernandez D, Jimenez-Garcia R (2012) Adherence to breast and cervical cancer screening in Spanish women with diabetes: Associated factors and trend between 2006 and 2010. Diabetes and Metabolism 38: 142–148	No	No health literacy/numeracy measure	
Mbaezue N, Mayberry R, Gazmararian J, Quarshie A, Ivonye C, Heisler M (2010) The impact of health literacy on self-monitoring of blood glucose in patients with diabetes receiving care in an inner-city hospital. Journal of the National Medical Association 102: 5–9	No	Unclear proportion T1DM	Contacted to separate out T1 or details regarding proportion, no further details available.
Moore PA, Weyant RJ, Mongelluzzo MB, et al. (1998) Type 1 diabetes mellitus and oral health: assessment of tooth loss and edentulism. J Public Health Dent 58: 135–142	No	No health literacy/numeracy measure	
Moussa M, Sherrod D, Choi J (2013) An e-health intervention for increasing diabetes knowledge in African Americans. International Journal of Nursing Practice 19: 36–43	No	T1DM & T2DM but high proportion T2DM (>78%) and unable to separate out	Contacted 29/2/15 – unable to separate data.
Nguyen HT, Kirk JK, Arcury TA, et al. (2013) Cognitive function is a risk for health literacy in older adults with diabetes. Diabetes research and clinical practice 101: 141–147	No	Type of diabetes not classified but likely T2DM according to authors (>92% diagnosed over age 35 yr)	
Nicolucci A, Maione A, Franciosi M, et al. (2008) Quality of life and treatment satisfaction in adults with Type 1 diabetes: A comparison between continuous subcutaneous insulin infusion and multiple daily injections. Diabetic Medicine 25: 213–220	No	No health literacy or numeracy measure	
Ntiri W, Stewart M (2009) Transformative learning intervention: Effect on functional health literacy and diabetes knowledge in older African Americans. Gerontology & Geriatrics Education 30: 100–113	No	Type of diabetes not classified but likely T2DM (mean age 68 yr)	Contacted to verify type of diabetes, but no reply (29/2/15)
Nurss JR, el-Kebbi IM, Gallina DL, et al. (1997) Diabetes in urban African Americans: functional health literacy of municipal hospital outpatients with diabetes. The Diabetes educator 23: 563–568	No	T2DM	
Osborn CY, Cavanaugh K, Wallston KA, Rothman RL (2010) Self-efficacy links health literacy and numeracy to glycemic control. Journal of health communication 15 Suppl 2: 146–158	No	Likely T2DM – ethnic minority, mean age 54y 62% on insulin	Communication with R. Rothmann 29/2/15

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Appendix. *Continued*

Reference	Included?	Inclusion Criteria	Contact with author
Otero LM, Zanetti ML, Ogrizio MD (2008) Knowledge of diabetic patients about their disease before and after implementing a diabetes education program. Revista Latino-Americana de Enfermagem 16: 231–237	No	2/52 T1DM No health literacy/numeracy measure	
Patrakeeva EM, Romanova NN, Zalevskaya AG, Shlyakhto EV (2013) Poor numeracy as a limiting factor for successful treatment of type 1 diabetes mellitus (T1DM) patients on continuous subcutaneous insulin infusion (CSII). Diabetes 62	No	Insufficient information (Conference abstract) & not validated numeracy score	Correspondence with author via email
Piatt A, Valerio A, Nwankwo R, Lucas M, Funnell M (2014) Health literacy among insulin-taking African Americans: A need for tailored intervention in clinical practice. The Diabetes educator 40: 240–246	No	Mixed population – insufficient numbers T1DM	Correspondence with author
Riaz M, Basit A, Fawwad A, Ahmedani MY, Rizvi ZA (2014) Factors associated with non-adherence to Insulin in patients with Type-1 diabetes. Pakistan Journal of Medical Sciences 30: 233–239	No	Mean age 17.9y	
Rothman RL, DeWalt DA, Malone R, Persell SD (2004) Diabetes disease management program is more effective for patients with low literacy. Journal of Clinical Outcomes Management 11: 752–753	No	Review/Commentary T2DM	
Rubin DJ, Donnell-Jackson K, Jhingan R, Golden SH, Paranjape A (2014) Early readmission among patients with diabetes: a qualitative assessment of contributing factors. Journal of Diabetes & its Complications 28: 869–873	No	No health literacy/numeracy measure	
Schillinger D, Barton LR, Karter AJ, Wang F, Adler N (2006) Does literacy mediate the relationship between education and health outcomes? A study of a low-income population with diabetes. Public Health Reports 121: 245–254	No	T2DM	Contacted to recommend others – no recommendation
Stiles E (2011) Promoting health literacy in patients with diabetes	No	Literature review	
Subramanian U, Hofer T, Klamerus M, Zikmund-Fisher B, Heisler M, Kerr E (2007) Knowledge of blood pressure targets among patients with diabetes. Primary Care Diabetes 1: 195–198	No	No health literacy/numeracy measure Population likely T2DM (not specified) – age 68.9y with duration DM 12.6 yr	
Tenforde M, Nowacki A, Jain A, Hickner J (2012) The association between personal health record use and diabetes quality measures. Journal of General Internal Medicine 27: 420–424	No	Type of diabetes not specified. No health literacy/numeracy measure	
Trief PM, Cibula D, Rodriguez E, Akel B, Weinstock RS (2016) Incorrect Insulin Administration: A Problem That Warrants Attention. Clinical Diabetes 34: 25–33	No	Mixed population - insufficient numbers of T1DM	
Trief PM, Izquierdo R, Eimicke JP, et al. (2013) Adherence to diabetes self- care for white, African-American and Hispanic American telemedicine participants: 5 year results from the IDEATel project. Ethnicity & Health 18: 83–96	No	T2DM	
van der Heide I, Uiters E, Rademakers J, Struijs JN, Schuit AJ, Baan CA (2014) Associations among health literacy, diabetes knowledge, and self-management behavior in adults with diabetes: results of a dutch cross-sectional study. Journal of health communication 19 Suppl 2: 115–131	No	Predominantly T2DM	No response to email request for further data.
Veghari GR, Marjani A, Joshaghani H (2007) The study of diabetes mellitus in Gorgan, Iran. Saudi Medical Journal 28: 1300–1301	No	T2DM >70% No health literacy or numeracy measure	
Walker RJ, Smalls BL, Hernandez-Tejada MA, Campbell JA, Egede LE (2014) Effect of diabetes self-efficacy on glycemic control, medication adherence, self-care behaviors, and quality of life in a predominantly low-income, minority population. Ethnicity and Disease 24: 349–355	No	T2DM	
Wallace AS, Carlson JR, Malone RM, Joyner J, Dewalt DA (2010) The influence of literacy on patient-reported experiences of diabetes self-management support. Nursing Research 59: 356–363	No	T2DM	

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Appendix. *Continued*

Reference	Included?	Inclusion Criteria	Contact with author
Weltermann BM, Driouach-Bleckmann Y, Reinders S, Berndt P, Gesenhues S (2013) Stroke knowledge among diabetics: A cross-sectional study on the influence of age, gender, education, and migration status. BMC Neurology Vol 13 Dec 2013, ArtID 202 13	No	T2DM	
White RO, Eden S, Wallston KA, et al. (2015) Health communication, self-care, and treatment satisfaction among low-income diabetes patients in a public health setting. Patient education and counseling 98: 144–149	No	T2DM only	
Yan J, Liu Y, Zhou B, Sun M (2014) Pre-hospital delay in patients with diabetic foot problems: Influencing factors and subsequent quality of care. Diabetic Medicine 31: 624–629	No	2% T1DM – not separated out. No health literacy or numeracy measure	
Yekta Z, Pourali R, Aghassi MR, Ashragh N, Ravanyar L, Pour MYR (2011) Assessment of self-care practice and its associated factors among diabetic patients in urban area of urmia, northwest of iran. Journal of Research in Health Sciences 1: 33–38	No	T2DM	
Yun LS, Hassan Y, Aziz NA, Awaisu A, Ghazali R (2007) A comparison of knowledge of diabetes mellitus between patients with diabetes and healthy adults: A survey from north Malaysia. Patient education and counseling 69: 47–54	No	No secondary outcome Likely T2DM population but not specified	
Zhang XH, Wee HL, Tan K, Thumboo J, Li SC (2009) Is diabetes knowledge associated with health-related quality of life among subjects with diabetes? A preliminary cross-sectional convenience-sampling survey study among English-speaking diabetic subjects in Singapore. Journal of Chinese Clinical Medicine 4: 144–150	No	33% T1DM No diabetes endpoint (measured Quality of Life)	
Zaugg SD, Dogbey G, Collins K, et al. (2014) Diabetes numeracy and blood glucose control: Association with type of diabetes and source of care. Clinical Diabetes 32: 152–157	Yes		Contacted & suggested Vanderbilt group.