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REVIEW

# Barriers and Facilitators of Self-Management in Older People with Type 1 Diabetes: A Narrative Review Focusing on Cognitive Impairment

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**Abstract:** Over the past decades, life expectancy of people with type 1 diabetes has increased considerably, which brings potential challenges due to the process of aging. Cognitive aging and dementia, as well as reductions in visual acuity, hearing and dexterity, can influence the frequency and quality of daily self-management activities, including medication taking and insulin dosing, glucose self-monitoring, and healthy eating. This can increase the risk for hypo- and hyperglycemic events, which, in turn, may contribute to cognitive decline. Because there is a gap in understanding the barriers and facilitators of self-management in older adults with type 1 diabetes and the relationship to cognitive functioning, the authors 1) review the available literature on cognitive aging and type 1 diabetes, 2) describe what self-management in later adulthood entails and the cognitive functions required for effective self-management behaviors, 3) analyze the interaction between type 1 diabetes, cognition, aging, and self-management behaviors, and 4) describe the barriers and facilitators for self-management throughout the life span and how they may differ for older people. Potential evidence-based practices that could be developed for older adults with type 1 diabetes are discussed. There is need for further studies that clarify the impact of aging on T1D self-management, ultimately to improve diabetes care and quality of life.
**Keywords:** type 1 diabetes, self-management, cognition, aging

## Introduction

Life expectancy of people with type 1 diabetes (T1D) has increased significantly in most countries over the past decades due to advances in medical treatments and technological improvements in glucose monitoring and insulin delivery.[1,2] Consequently, an increased number of people with T1D reach older age (>65 years),[3] and may experience signs of typical aging processes, such as frailty, loss of autonomy, malnutrition, vision and hearing impairments, reduced dexterity, and age-related decline in cognition. All such factors may affect their engagement with, and capacity for managing, T1D-related behaviors (ie, diabetes self–management skills).[4–6]

Regardless of age, diabetes self-management can be cognitively complex and demanding,[7,8] since it requires the measurement and interpretation of glucose levels, the use of algorithms to adjust insulin doses based on current and trending glucose levels, and attention to current eating patterns and activity levels. Newer glucose monitoring and insulin delivery technologies, including continuous glucose monitoring (CGM) devices and advanced hybrid closed-loop (HCL) systems hold promise for automating and simplifying these self-management requirements. However, both traditional



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and newer technology require interpretation and thoughtful decision-making based on extensive insulin and glucose data that may fluctuate over time, as well as uncaptured lifestyle, personal preferences, and behavioral factors, which can be challenging at any age.[7]

All aspects of T1D self-management require adequate cognitive function.[7,9,10] They include the complex tasks of taking medication, monitoring of glucose levels, reducing risk of hypo- and hyperglycemia and long-term complications, problem solving, and healthy nutrition and physical activity.[9] Of these, little is known about healthy nutrition (eg, meal planning, matching insulin with carbohydrate or food intake, adequate protein intake and interpreting nutrition labels),[8,11] and physical activity – both of which may promote improved glucose control,[12] improved appetite,[13] and prevent frailty[14] in older adults with T1D. Because T1D is associated with increased risk for cognitive decline, over and above the expected cognitive changes associated with normal aging, this may interfere with self-management, which then may lead to (additional) glycemic dysregulation, potentially further worsening cognitive functioning.

In view of the high cognitive demand needed for T1D self-management, it is imperative to understand the cognitive profile of older adults with T1D in addition to the expected age-related changes in cognition. Recently, the 32-year DCCT/EDIC T1D follow-up study showed that cognitive decline, particularly in psychomotor and mental efficiency, was equivalent to nearly 10 years of advanced cognitive aging,[15] with higher lifetime HbA1c, more episodes of severe hypoglycemia, and elevated systolic blood pressure associated with greater cognitive decline.[15] In older adults with T1D, the presence of severe hypoglycemia, in particular, can impact cognition.[16]

This review summarizes the barriers and facilitators of self-management in older individuals with T1D, with a particular focus on the role of cognition. We review the cognitive literature in T1D, discuss the most important aspects of self-management and the cognitive functions that may underly these behaviors, analyze the interaction between cognition, aging, and T1D self-management behaviors, and describe the barriers and facilitators for self-management competencies throughout life and how they may uniquely impact older people with T1D. While type 2 diabetes (T2D) is also related to cognitive alterations with aging, other publications have discussed this in detail, eg, see.[17] Therefore, we will focus exclusively on T1D.

## Cognition and Aging in T1D

Cognition refers to the conscious and unconscious mental processes by which knowledge is accumulated, including memory, attention, language, executive functions, motor control, sensory perception, and speed of information processing (Table 1).[18] To further elaborate, executive function is an umbrella term that includes self-monitoring, problem–solving, impulse control, judgment, and the ability to learn novel behaviors. Throughout life, T1D is associated with small, but significant, cognitive decrements compared to adults without diabetes particularly on measures of attention, psychomotor efficiency, and executive functions.[17] This section will briefly address expected age-related changes, as well as pathological cognitive decline and dementia in older adults with T1D.

### Cognitive Changes Expected with Aging and the Role of Cognitive Reserve

With healthy aging, some cognitive functions are expected to decline, such as processing speed and new learning, with minimal impact on the ability to perform daily activities.[19] In contrast to normative age-related cognitive decline, pathological cognitive aging is marked by cognitive decline that is greater than expected due to aging alone (ie, Mild Cognitive Impairment; MCI) and impacts daily functioning (ie, dementia). In MCI, cognition is impaired in one or more cognitive domains compared to age-matched normative data, with no or minimal impairment of instrumental activities of daily living.[20] MCI can be divided into amnestic and non-amnestic and is associated with a higher risk of conversion to dementia, with amnestic MCI being especially associated with risk for Alzheimer disease.[21] In dementia, multiple domains of cognition are impaired, along with impairment in activities of daily living,[22] regardless of underlying pathology (eg, Alzheimer's disease, Lewy Body disease, and vascular disease).

There is substantial heterogeneity in the cognitive aging process (normal and pathological) in the general population, in which inter- and intra-individual risk and protective factors play an important role. Some factors, including level of education, intelligence, socioeconomic status, and lifestyle factors, such as regular exercise and good nutritional habits,[23,24] may attenuate the effect of brain aging.[24] Collectively these factors have been included within the concept

**Table 1** Impact of Cognitive Decline on Self-Management in Older Adults with T1D

| Cognitive Domain/ Construct | T1D-Related Impairment[a] (Compared to Controls without Diabetes) | Aging-Related Changes[b] | Barriers to Self-Management in T1D | Potential Facilitators[c] |
|---|---|---|---|---|
| **Executive Functioning**<br>Set of cognitive processes: problem solving, judgement, response inhibition, thinking abstractly, and self-monitoring | Worse performance | Expected decline | Difficulty with problem solving when familiar solutions are not effective (eg, unexpected changes in glucose)<br>Difficulties with self-management skills and complex behavior involving multiple steps (eg, determining mealtime insulin dosing) | Automated insulin delivery; Fixed mealtime insulin dosing eg for small medium and large meals |
| **Attention**<br>Actively process information in the environment while ignoring other information | Worse performance | Expected decline, mainly in divided attention | Difficulty with the ability to control, shift and divide attentional focus for complex diabetes management tasks<br>Difficulty in monitoring blood glucose<br>Difficulty calculating insulin doses eg, in a noisy restaurant | Simpler insulin and monitoring regimen, use of CGM, smart insulin pens, and automated insulin delivery<br>Taking a "time out" and reducing distractions when doing diabetes tasks |
| **Episodic memory**<br>Memories that are localized in time and space (personal everyday events) | Worse performance, but relatively spared compared to performance in domains more directly related to vascular damage (such as processing speed and attention) | Expected decline | Difficulty monitoring food intake, remembering medical advice and appointments, taking medication and engaging on healthy lifestyle. | Journaling, use of lists and external aids.<br>Use of a voice-activated personal assistant; remote monitoring<br>Automated insulin delivery. |
| **Prospective memory**<br>Memory for future intentions | Preserved, unless during hypoglycemic events | Expected decline | Difficulty in taking medication at certain times of the day, remembering to attend a scheduled appointment.<br>Remembering to change infusion set or charge insulin pump. | Use of cues or reminder systems as aids, such as alarm clock; voice control personal assistants, device alarms/reminders |

(*Continued*)


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**Table 1** (Continued).

| Cognitive Domain/ Construct | T1D-Related Impairment[a] (Compared to Controls without Diabetes) | Aging-Related Changes[b] | Barriers to Self-Management in T1D | Potential Facilitators[c] |
|---|---|---|---|---|
| **Working memory**<br>Temporary storage and manipulation of information | Preserved | Expected decline, particularly for mental manipulation | Difficulty with mental math, or remembering one thing while doing another (eg, counting carbohydrates while having a conversation) | Simpler insulin and monitoring regimen, automated insulin delivery or devices that calculate insulin doses and record insulin injections administered (eg smart/ connected insulin pens) Use of external memory aids, such as and electronic organizers with alarm and lists. Doing one task at a time |
| **Processing speed**<br>The rate at which information is perceived and processed. | Worse performance | Expected decline | Difficulties with self-management skills performed under time constraints<br>Being unable to retain information when presented too quickly | Use of automated technology<br>Slowing down when completing diabetes tasks<br>Double checking dose calculations<br>Allowing extra time during medical visits |
| **Vocabulary and Verbal abilities**<br>Ability to understand and use language, crystalized knowledge | Preserved | Preserved | - | Preserved domain that can be used for planning of compensatory strategies. Information acquired over a lifetime available on which to base decisions. Extensive experience with diabetes and its consequences |
| **Sensory perception and motor control skills**<br>Object recognition, visual and auditory acuity, fine motor planning and visuo-perceptual movements | Preserved, unless microvascular complications | Expected decline in visual acuity and hearing. Diminished fine motor dexterity and coordination. | Difficulty with safe medication use/ administration and hearing low glucose alarms | Voice control personal assistants; Use of low vision and hearing aids, larger objects and letters<br>Use of insulin pump rather than injections (fine motor dexterity) |

**Notes**: [a]Group differences in cognition attributed to T1D are generally mild, with larger differences in those who develop diabetes earlier in life and for individuals with vascular risk factors (eg, high HbA1c, diabetes complications, hypertension). [b]Expected aging-related decline, large individual differences in normal cognitive aging. [c]Facilitators depend on the severity of impairment. Cognitive training with compensatory strategies can be used for T1D and aging related cognitive changes. Training of care partner and professional care might be necessary depending on the regime complexity, comorbid conditions and severity of cognitive impairment (eg, dementia).


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of cognitive reserve. A higher cognitive reserve, or "surplus" in cognitive abilities, may delay the onset of noticeable cognitive decline, which helps explain resilience or susceptibility to aging and pathological cerebral changes.[25] Little is known about factors that protect against age-related or accelerated cognitive decline in older adults with T1D.

## Aging-Related Changes and Cognitive Decline in T1D

Despite increasing life expectancy, relatively little is known about the profile of cognitive decrements in older people with T1D. A recent cross-sectional study comparing older adults with T1D (n=734; mean age 67.20±6.25 years), T2D (n=232; mean age 68.70±7.04 years) and no diabetes (n=247; mean age 68.70±7.0 years), demonstrated that people with T1D had lower scores on total cognition, language, executive function/psychomotor processing speed, and verbal episodic memory, compared to individuals without diabetes, but not when compared with T2D.[26] A 4.1-year follow-up study of those with T1D vs controls (40 T1D/36 controls; T1D mean age at baseline 60.4±6.0 years) did not show an accelerated decline compared to controls.[16] It did, however, demonstrate that those with one or more severe hypoglycemic or cardiovascular events during follow-up showed accelerated decline in processing speed and overall cognition, compared to their counterparts without such events.[16] The DCCT/EDIC 32-year cognitive follow-up (n=1051; median age 59 years; range 43–75) showed accelerated decline in processing speed and mental efficiency,[15] particularly between the 18 year and 32 year visits. The main predictors of decline were a higher lifetime HbA1c, more episodes of severe hypoglycemia, and a higher systolic blood pressure, suggesting an important vascular contribution to decline (Figure 1). Interestingly, those participants with the lowest risk factor exposure (ie, lower HbA1c, no severe hypoglycemic events, normal systolic blood pressure) did not experience any decline in psychomotor efficiency over the 32-year follow-up period, possibly suggesting that controlling these factors can protect individuals from accelerated decline.

## Risk of MCI and Dementia in T1D

The data discussed in the previous paragraph suggest that at least a subset of older adults with T1D may have accelerated cognitive aging, which could evolve into MCI or dementia. Despite these conditions posing serious implications for self-management, few studies have investigated these conditions in T1D. A study including 201 older participants with T1D (age >65 years; mean age 68.29±6.15 years) showed that clinically significant cognitive impairment (two or more test performances of ≥1.5 standard deviations below the mean based on normative data) was present in 50% of the group,[27] with the majority showing a non-amnestic profile. The DCCT/EDIC defined possible MCI as scoring 21 or lower on the Montreal Cognitive Assessment (MoCA), a commonly used cognitive screening test. They showed that 6% of the sample met the criteria for MCI,[15] although the chosen cut-off is very conservative and the percentage likely represents an

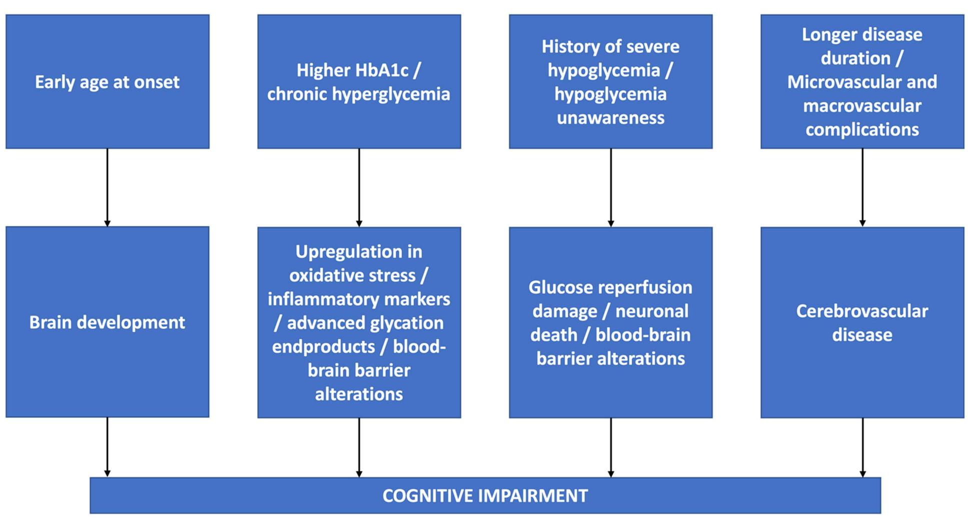


**Figure 1** A schematic overview of factors related to cognitive impairment in older people with T1D. On top are factors that have been found to be related to cognitive impairment. In the middle, some factors have been added which can be considered a consequence of T1D and may play a mediating role in these factors relating to cognitive impairment.

underestimation. Indeed, a reanalysis of the DCCT/EDIC data showed the optimal cut-off for cognitive impairment was 25 and lower, indicating the percentage of participants with cognitive impairment might be higher than 6%.[28] In another sample of older adults with T1D, the overall accuracy of the MoCA was low, but a cut-off of <27 was found to be most accurate.[29] More studies determining MCI prevalence in older adults with T1D and its effect on self-management tasks are needed. These low rates of MCI may represent an underestimation of cognitive burden in T1D because of "survivor bias". That is, those with better glycemic control, and less micro- and macroangiopathy may be more likely to survive into older adulthood as well as function better cognitively because they have fewer biomedical risk factors. It is also known that older participants tend to be better educated, have better socioeconomic status, and lower depression scores.

Regarding dementia, a British medical records study including 343,062 people with T1D aged 30 and older, found 10,786 had a diagnosis of any dementia, representing an adjusted relative risk of 1.65 with a 95% confidence interval (CI) ranging from 1.61 to 1.68.[30] This was mainly driven by vascular dementia, with a relative risk of 2.21 (95% CI: 2.13–2.28; 3885 cases), while the increase in risk of Alzheimer's disease was small (1.10 [95% CI: 1.05–1.15]; 2113 cases). This considerably higher hazard ratio of vascular dementia relative to Alzheimer's disease was corroborated by a smaller Danish national records study in adults 65 and older (1.51 [95% CI: 1.17–1.95] versus 1.11 [95% CI: 0.95–1.32]).[31]

In summary, there is some evidence that having T1D increases risk of MCI and dementia, likely due to a vascular etiology. This mirrors T1D-related cognitive decrements found across the life-span, which are heavily skewed towards domains that are sensitive to vascular cerebral damage, such as processing speed, attention, and executive functions, with relative sparing of memory.[17]

## Possible Mechanisms Underlying Cognitive Alterations in T1D

Given the limited literature on cognitive functioning and dementia in older adults with T1D, the mechanisms responsible remain unclear. In general, in adolescents and adults with T1D, cognitive dysfunction is associated with early age of T1D onset and chronic hyperglycemia which is associated with the development of microvascular and macrovascular complications.[15,17] It is known that chronic and reactive (after hypoglycemia) hyperglycemia can cause a cascade of biomedical reactions, including increased inflammation, oxidative stress, and advanced glycation end products (Figure 1),[32–34] which may affect brain structure and functioning. While it is likely that these factors, and specifically chronic hyperglycemia, play a role in older adults, other factors should also be considered. The 32-year DCCT/EDIC study showed that the observed decline in psychomotor speed and mental efficiency was related to higher lifetime HbA1c (chronic hyperglycemia), episodes of severe hypoglycemia, and higher systolic blood pressure (Figure 1).[15] In other samples, poorer cognition has also been shown to be associated with these risk factors, as well as microvascular complications and cardiovascular events (Figure 1).[16,27] Mechanisms specific to dementia are scarce, but also seem to be related to HbA1c,[35] although not to the presence of retinopathy.[36] Taken together, these data suggest a strong vascular component, which matches the speed-related profile of cognitive alterations and the significantly increased risk of vascular dementia in T1D, but also points towards a contribution of severe hypoglycemia as an important risk factor that should be prevented. Figure 1 summarizes these mechanisms and details some of their biomedical consequences that could be related to cognitive alterations.

The literature to date suggests that optimal control of vascular disease risk factors, including HbA1c, and minimizing exposure to severe hypoglycemia, across the lifespan will maximize the likelihood of successful cognitive aging in T1D. Of note, EDIC participants with average HbA1c of 6.5%, systolic blood pressure of 100 mmHg and no severe hypoglycemic events, did not experience any cognitive decline over the 32-year follow-up period. Adherence to this level of control, however, requires substantial resources, patient burden and access to optimal health care, and is not possible for all T1D adults.

# Type 1 Diabetes-Related Self-Management

According to the Association of Diabetes Care and Education Specialists, there are seven key diabetes self-management behavioral domains that are associated with improved clinical outcomes.[8] In no particular order, these competencies include: (1) taking medication, (2) healthy eating, (3) being physically active, (4) problem-solving, (5) monitoring

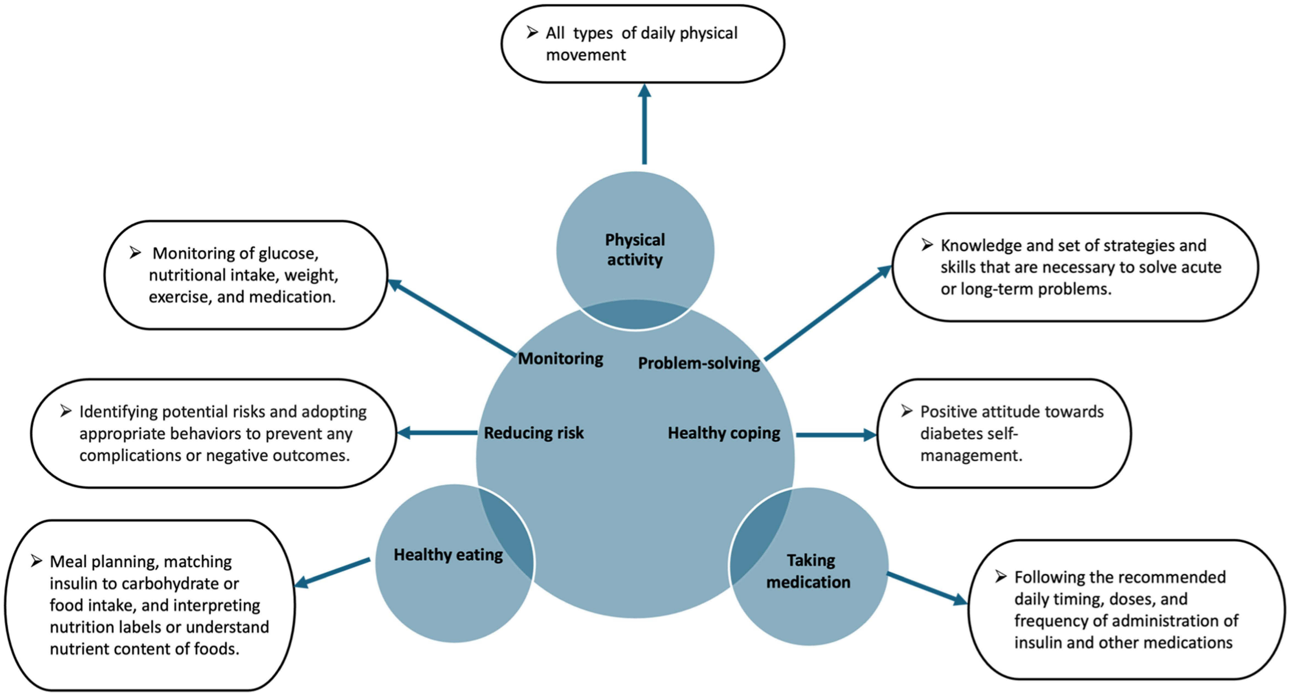


**Figure 2** A schematic overview of the core competencies for type 1 diabetes self-management, where coping, reducing risk, problem solving, and monitoring were placed at the center. Competencies, including healthy eating, taking medication, and physical activity, in part are dependent on the other competencies.

glucose, (6) reducing risk of diabetes complications and (7) healthy coping.[8] Several cognitive functions (eg, executive function, memory, attention), and applied skills (eg, numeracy, literacy) may be involved in these competencies (Table 1; Figure 2).[7,37,38]

## Taking Medication in T1D

Taking medication is an essential component of T1D self-management and encompasses behaviors like following the daily recommended timing, dosage, and frequency of insulin administration.[8] Given the increased risk of hypoglycemia in older adults with T1D,[39] the use of CGM is recommended, since wide glycemic excursions, including episodes of hypo- and hyperglycemia, can occur at both high and low HbA1c levels. The HbA1c goals should be individualized, with the recommended HbA1c goal of 7.0–7.5% for cognitively and otherwise healthy older adults, and <8.0% for those with significant cognitive and/or functional impairments.[39] For those with moderate to severe cognitive impairment, glucose targets should be guided based on avoiding hypoglycemia and symptomatic hyperglycemia.[39]

Successful adherence to any insulin regimen (complex or simplified) will require various cognitive abilities and related skills, including numeracy (ability to comfortable work with numbers), health literacy, and executive functioning.[8,38] Of these, numeracy is particularly important since many adults with T1D count/estimate carbohydrates and determine insulin doses based on their current blood glucose level and carbohydrate-to-insulin ratio. Smart/connected insulin pens and insulin pumps can perform these calculations. However, because the routine use of complex insulin regimens may become too cognitively demanding for older adults with or without cognitive decline, a simplified regime may be necessary.[7,40] This should be based on an individualized decision between the older person with T1D and health care provider, based on actual problems with self-management. Examples include the use of fixed mealtime boluses if eating patterns are established and reliable, or ultrafast–acting insulin up to 20 minutes after each meal to accommodate for fluctuating meal intake, or supervision/assistance by caregiver.[41] However, eventually, with progressing cognitive decline, self-management may need to be assumed by caregivers. Depending upon the availability of caregiver support, automated insulin delivery systems can be used, and their use is associated with less time in hypoglycemia.

## Healthy Eating and Physical Activity in the Context of Self-Management in Older Adults with T1D

In T1D, a healthy diet and physical activity are fundamental for glycemic control at any age, including regular exercise, choosing healthy foods, and proper meal planning. All of these involve optimal nutrition and protein intake, carbohydrate counting (when possible), portion management and understanding nutrition label information.[8,39] In older adults with T1D, healthy eating can become more challenging due to a variety of factors, including cognitive decline, a change in appetite, decreased olfactory and gustatory capacity, poor dentition or vision, polypharmacy, financial limitations, cultural preferences, and problems with access to healthy food.[6,42,43]

In T1D, changing eating habits can result in altered insulin needs, for which insulin regimens need to be adjusted. Such changes can make blood glucose regulation less predictable and self-management more cognitively demanding, which may lead to more hypo- and (reactive) hyperglycemic events. Changes in diet quality and/or glucose variation may also influence daily cognitive functioning and promote cognitive deterioration, as poor nutrition has been linked to cognitive decline irrespective of the presence of T1D.[44] Healthy eating requires planning, numeracy, attention, memory, and inhibition. Indeed, memory and more complex attentional functioning are correlated with T1D self-management skills, such as carbohydrate counting, and calculating insulin-dose adjustments based on serving sizes and nutrition labels.[37]

Physical activity in relation to diabetes self-management remains understudied in older adults with T1D. However, it has been shown that regular light exercise can improve insulin sensitivity and glycemic control in adults with T1D,[12] highlighting the importance of physical activity. With aging, independent of T1D, physical activity can become more difficult, due to many factors, including isolation, malnutrition, overweight/obesity, risk of falls, loss of interest, and general frailty.[45,46] In older people with T1D, microvascular complications, such as neuropathy or retinopathy, as well as the risk of hypo- or hyperglycemia can pose barriers to being physically active.[47] In older adults without T1D, physical activity has been found to have a bidirectional relationship with cognitive function, including memory and executive functions.[48] In older people with T1D, unfortunately, the relationship between cognition and physical activity, especially related to self-management, has not yet been studied.

## Problem Solving, Monitoring, Reducing Risk, and Healthy Coping

The four competencies of problem solving, monitoring, reducing risk of complications, and healthy coping strategies are aimed at limiting acute hypo- and hyperglycemia, diabetic ketoacidosis, and long-term complications. Cognitive decrements and accelerated decline in older adults with T1D should also be a focus of risk reduction as long-term exposure to elevated blood glucose is associated with increased cognitive decline and dementia risk.[35,49]

In T1D, *problem solving* refers to the knowledge and set of strategies and skills that are necessary to solve acute or long-term problems.[8] It involves identifying the problem (eg, hypoglycemia), developing appropriate solutions, acting on a solution, and monitoring.[8] For T1D, monitoring involves the examination of glucose levels, blood pressure, nutritional intake, weight, exercise, and medication.[8] The results can be used to develop appropriate solutions and action through behavior changes.[8] For example, glucose self-monitoring provides data that can be used to evaluate the effectiveness of T1D self-management and guides adjustments in diet, insulin dosage, exercise, and medication use.[50] The use of CGM is an essential component of automated insulin delivery systems, which can suspend insulin delivery when hypoglycemia is predicted, thereby reducing time in hypoglycemia. Automated insulin correction doses can also be given to reduce time in serious hyperglycemia. Reducing risks is linked to the previous two competencies, as well as engaging in recommended screening for early signs of complications (eg, eye exams, kidney function tests, foot checks), and treating hypertension and hyperlipidemia. These interventions reduce the risk of long-term complications.[8] The ability to mitigate these risks is fundamental for healthy aging, continued effective T1D self-management and overall quality of life. *Coping* in the context of T1D self-management refers to the individual's set of mechanisms to deal with all aspects of T1D.[8] For example, a study in younger persons with T1D and their caregivers showed a pattern of productive (acceptance, planning ahead, social support) and non-productive (avoidance/disengagement, insulin rationing) coping strategies.[51] Non-productive or unhealthy coping can lead to significant increases in diabetes distress and symptoms of depression and anxiety. These, in turn, can influence other aspects of self-management, ultimately leading to reduced glycemic control. In contrast, healthy coping may reduce distress and improve overall self-management. Healthy coping, as a potential protective factor, has not been systematically studied in older people with T1D, despite the fact that they are similarly affected by diabetes-related stress as their younger peers.[52]

The cognitive skills related to the success of these seven competencies include memory, attention, and executive functions, such as adequate judgement, planning, self-monitoring, problem solving, as well as inhibition of unhealthy behaviors.[53] In older adults with T1D, these competencies can be more challenging in the presence of financial difficulties, reduced dexterity, vision and hearing impairment, and cognitive decline.

## Recent Advances in Technology to Reduce Cognitive Burden of T1D Self-Management

As stated, self-management in T1D is cognitively demanding and is dependent on the close interplay between memory, attention, executive functions, processing speed, and visual/motor skills. Technologies, such as CGM and automated insulin delivery (HCL) systems, may help improve T1D self-management in older people by reducing its cognitive burden when used appropriately. These technologies, their cognitive burden, and other potential treatment solutions for older adults with T1D and cognitive impairment have been summarized in Table 2.

There is evidence to suggest that regardless of presence or absence of cognitive decline, older people with T1D can successfully use advanced technology,[54] albeit potentially with additional device training.[55] For example, in a study of people with T1D aged 60–83 years, CGM effectively reduced time spent in hypoglycemia, severe hypoglycemic events and glycemic variability after 6,[54] and 12 months,[56] with no difference in benefit for those with and without cognitive impairment. Using HCL with 30 older adults (mean age 67±5 years; range 60–75), McAuley et al demonstrated

**Table 2** Overview of Treatment Options and Their Cognitive Burden

| Treatment Option | Description | Cognitive Burden | Potential Solution for Older Adults with Cognitive Impairment |
|---|---|---|---|
| Multiple daily injections | Use of 1–2 basal long-acting insulin injections daily with multiple bolus rapid-acting insulin injections to be administered around meals or snacks and for correction of hyperglycemia. | Estimating mealtime insulin needs (using carbohydrate counting if possible), glucose monitoring with fingersticks or CGM, adapting insulin dosing for physical activity. | Use of rapid–acting insulin for up to 20 minutes after each meal if food intake is unreliable. Fixed mealtime boluses may be considered if eating patterns are established and reliable.<br>Use of Smart/connected insulin pens (record insulin dosing and can provide reminders)<br>Use of automated insulin delivery (HCL) |
| Insulin pump | Devices that provide continuous insulin infusion. | Estimating mealtime insulin needs (using carbohydrate counting if possible), glucose monitoring with fingersticks or CGM, adapting insulin dosing for physical activity. Ordering and managing pump supplies. Troubleshooting malfunctions. | Use of automated insulin delivery (HCL) as described below |
| Continuous Glucose Monitoring | Devices that provide real-time glucose readings every 5 minutes. | Understanding sensor data, including glucose trends and alarms/alerts for hypoglycemia and serious hyperglycemia. Ordering and managing CGM supplies. Troubleshooting malfunctions. | Use of alarms to warn of impending hypoglycemia and serious hyperglycemia<br>Share real-time glucose data with care partner |

(*Continued*)

**Table 2** (Continued).

| Treatment Option | Description | Cognitive Burden | Potential Solution for Older Adults with Cognitive Impairment |
|---|---|---|---|
| Automated insulin delivery using hybrid closed loop (HCL) systems | Advanced systems that automatically adjust insulin delivery based on CGM readings. | Counting carbohydrates or entering mealtime doses or size of meals for optimal use, Use of functions such as exercise/activity mode, understanding sensor data. Ordering and managing pump/CGM supplies. Troubleshooting malfunctions. | Reduced cognitive burden (systems provide automatic correction boluses of insulin when needed, including when an individual does not bolus for a meal). Needs adequate training for both the T1D older adult and their care partner Share real-time glucose data with care partner |
| Automated insulin delivery using closed loop systems | No commercially available system is completely automated. Such systems are under development. | Reduced cognitive burden. No carbohydrate counting or decision-making related to insulin dosing. Ordering and managing pump/CGM supplies. Troubleshooting malfunctions. | Cognitive burden greatly reduced. Need adequate training for both the T1D older adult and their care partner |

a significant improvement of time in target glucose range (TIR) and a small but significant decrease in hypoglycemia (time below range) compared with sensor augmented pump therapy.[35] Boughton et al, in a 16-week HCL versus sensor-augmented pump therapy crossover trial that included 37 older adults with T1D (median age 68 years; IQR 63–70), found clinically significant improvements in TIR and a reduction in HbA1c when using HCL, without increased hypoglycemia.[57]

HCL systems reduce or suspend insulin delivery when hypoglycemia is predicted to occur, thereby reducing time in hypoglycemia. Many currently available advanced HCL systems also provide "autocorrection" doses when glucose readings are rising, so even in adults who forget to bolus for eating, glycemic control improves. Significant improvements in glycemic control have been reported recently for a commercially available system that requires only the person's weight and the time and size of the meal (usual, smaller or larger) to be entered. Unfortunately, this has not yet been tested specifically in older adult but seems quite promising, particularly because no carbohydrate counts are required (Table 2).[58] In development are fully closed-loop systems that will administer insulin with or without glucagon automatically, including at mealtimes, with the goal of keeping all glucose levels within the target range.[59,60]

HCL systems are an improvement over multiple daily injections or insulin pump use without automated insulin delivery, as they reduce the cognitive burden of self-management. However, these systems still can be difficult for older adults with cognitive, dexterity and vision problems. Some older adults may have difficulty adopting new technology, may require more time and effort when learning new routines and tasks, and may have increased difficulty trouble-shooting problems that can arise with HCL systems. Further, all available technologies require application of sensors and/or insulin infusion sets, and regular care and maintenance of the devices (eg filling insulin pump cartridges) which can be difficult for those with disabilities. Challenges include software updates, charging devices, changing CGM components, ordering pump and CGM supplies, recognizing occlusions, and the need to rotate sites. While the HCL devices take over several aspects of self-management, competencies including coping, healthy nutrition, and physical activity also remain. Larger trials that include important subgroups (eg, >75 years old, cognitively impaired, frail, lower education/literacy, and greater racial/ethnic diversity) and caregivers, are needed to study training approaches, evaluate the effectiveness and safety of these different devices and examine how competencies, such as coping, healthy eating, and physical activity can be promoted in the aging T1D population to reduce cognitive decline.

## Interaction Between Cognition, Aging and Self-Management

Many of the cognitive domains that are most susceptible to aging-related deterioration, such as planning, mental flexibility, inhibition, and memory are fundamental for T1D self-management. Due to the complexity of these activities, even minor cognitive impairment can have a major impact. Indeed, in a study with 201 older adults with longstanding T1D, the severity of cognitive deficits was associated with both diabetes management and performance of instrumental activities of daily living,[34] which is similar to findings in T2D,[61,62] indicating a relationship between cognition and self-management.

Not only did the DCCT/EDIC study group show 10 years of accelerated cognitive aging by study year 32,[15] but neuroimaging showed that people with T1D have structural abnormalities equivalent to 4 to 9 years of accelerated brain aging.[63] Even though self-management can be assumed to be a highly overlearned and reinforced skill and older adults with T1D have been "doing it" for decades, older people with T1D are as much affected by diabetes-related stressors as their younger peers.[52] Add to this accelerated cognitive and brain aging, and it is conceivable that self-management, including monitoring, insulin injection administration and device control, may become more difficult, and lead to worse glycemic control. How the effects of accelerated aging interact with self-management is largely unknown. Larger studies are needed in diverse international populations that incorporate both cognition and self-management measures. Especially important to include in such studies are assessments of healthy coping, healthy eating and physical activity, as these domains of self-management cannot be controlled by devices.

Importantly, hypoglycemia is known to be dangerous for older individuals, as it can lead to falls, fractures, hospitalizations, vascular complications and mortality, as well as additional cognitive decline.[15,27,64] This decline can further complicate self-management and cause deterioration in glycemia, which can increase the risk of pathological cognitive decline.[65] Depending on the level of cognitive reserve and care partner support, however, there will be individual variation as to when cognitive aging and neurodegeneration start to affect self-management. Clinical follow-up by providers, involvement and continued monitoring by caregivers will be needed, as well as a proper understanding of each person's barriers and facilitators of T1D self-management, which will likely change over time. The dynamics of this cycle are shown in Figure 3.

## Barriers and Facilitators of Self-Management

Table 1 summarizes barriers and potential facilitators of self-management in T1D, including the development of cognitive, visual and hearing impairments, availability of advanced T1D treatment options, reduction in dexterity and other physical functions, an increased comorbid medical conditions, polypharmacy, an increased risk of malnutrition, and, for many, the need for caregiver support. Some facilitators may offset these potential difficulties, including expertise

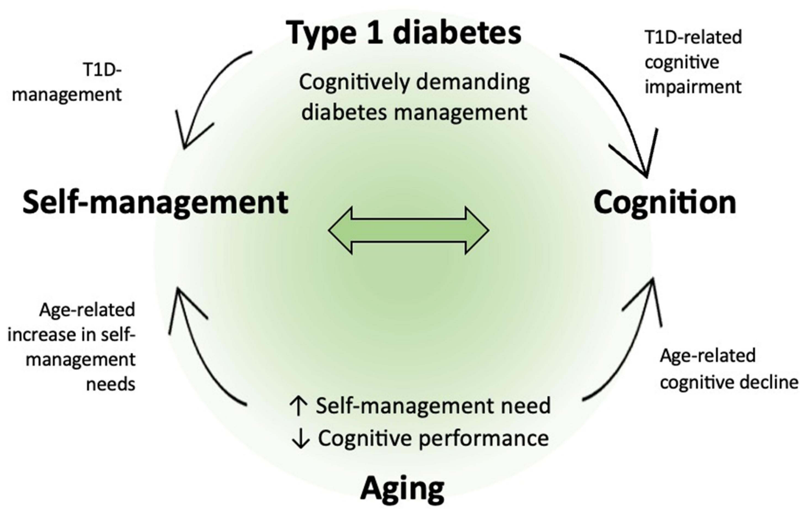


**Figure 3** Cycle model of self-management, cognition, and aging in type 1 diabetes. There is a bidirectional relationship between self-management and cognition in T1D: cognitive performance influences the quality of diabetes management, and suboptimal diabetes management may also increase the likelihood of worsening cognitive performance. Both the presence of T1D and aging will affect this relationship between cognition and self-management, enhancing the dependence and strength of this bidirectional association: cognitive difficulties associated with T1D negatively impact the self-management needs generated by the disease; with age-related decline, self-management ability deteriorates and the need for planned self-management increases considerably.

in T1D self-management, cognitive reserve, preserved cognitive functioning, use of technological advancements, modification of the insulin and glucose monitoring regimen, personalized dietary plans, nutrition assistance programs, and programs to offset medication cost. These are mostly T1D-related or general medical barriers and facilitators. Psychosocial facilitators and barriers may include support from family and friends, personality traits, loneliness, stress of limited financial resources or limited access to food or care, and mood states, such as depression or dysphoria.[66]

Due to lack of research, barriers and facilitators from the perspective of the older person with T1D are unclear. It is possible that some older adults with T1D may perceive effects of cognitive decline before decline is captured on neuropsychological testing, or before others' observations. A qualitative study including 29 older participants with T1D (73.4±4.5 years) identified various themes that acted both as a barrier and a facilitator. For example, technology, including CGM, was mentioned as a barrier (challenging to understand, needing to learn to work with the device), but also as a facilitator (improves glycemic control, takes over some aspects of self-care). Self-reliance, self-advocacy and survivors' mentality were identified as facilitators. On the contrary, worries about declining (cognitive) and physical health and getting help or giving control to a caregiver were described as barriers.[67] Another recent study assessed burden and benefits of CGM use in T1D, including 102 participants 65 and older.[68] In non-users, relative to users, there was a stronger belief that CGM use was a burden. For example, non-users more frequently reported that CGM information was too hard to understand, and that it causes too much worry. Only 43% reported feeling more secure with CGM, and 20% reported feeling that with CGM they would take better care of their T1D.[68] Interestingly, about 59% of the non-users believed that the CGM would make diabetes care easier and that it would take care of their low blood glucose. However, in CGM-uses, these percentages were considerably and statistically significantly higher.[68,69]

Unfortunately, these studies have included ethnically non-diverse people with higher SES, many using CGM. Barriers and facilitators in people who are non-white, lower educated, and of lower SES, including from developing countries, should be studied. In such studies, progressive cognitive decline should also be included. How do older people with T1D think about having caregivers taking over more self-management tasks, and how can this be done safely are important unanswered questions. Furthermore, caregivers can serve as facilitators, but also as barriers to self-management as they will not have the life experience of the person with T1D, and will need to be trained to provide T1D self-management. They may also develop age-related impairments. More studies are needed to gain a better understanding of the barriers and facilitators of self-management from the perspective of older people with T1D and their families and caregivers.

## Future Studies

Given the increasing life-expectancy of people with T1D and the need for complex T1D self-management, there is a need for research that addresses the gap in knowledge in the association between aging, cognition, and self-management behaviors. Future studies characterizing the heterogeneous cognitive profiles in this population will help define personalized target areas for rehabilitation interventions, caregiver involvement, and need for changes in insulin regimens/ delivery methods over time. Research should also focus on aging-related planning, and investigating T1D-related cognitive demands and the usability and effectiveness of new technologies, including advanced automated insulin delivery systems, to inform the establishment of self-management support for older adults with T1D and their caregivers. Finally, the role of healthy coping, nutrition, and exercise in older adults with T1D remains largely unexplored. Further research, both qualitative and quantitative, is required to better understand the different and changing needs of this unique population, including identifying those at risk for deteriorating self-management. Also needed is research that identifies facilitators of continued self-management independence, and strategies that can optimize support during transition periods (eg, declining cognition, starting new diabetes technologies, caregiver taking over diabetes management).

## Conclusions

Advancements in T1D treatment and self-management technologies have dramatically increased longevity of individuals with T1D. With aging, and specifically with declining cognition, new challenges in self-management often emerge. The usability and effectiveness of new technological devices by older adults with T1D with varying degrees of cognitive and physical impairments needs further study. A greater understanding of the changing barriers and facilitators in the management of T1D in older adults, both qualitative and quantitative, will help lead to better approaches for their diabetes management and, in turn, to improved quality of life.

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## Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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