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Control Architecture in Power Wheelchairs

A practical clinical guide for seating & mobility professionals — translating control into participation.

Contents

Introduction

Why this guide exists

Selecting an alternative drive control for a power wheelchair is often approached as a device choice: a standard joystick, a mini joystick, a head array, switches, eye gaze…

In practice, experienced clinicians know that control selection is rarely that simple.

A user may *drive* successfully in a quiet clinic, but still struggle in narrow hallways at home. A user may drive well, but cannot access tilt or seat elevation independently. A control method that works for ten minutes may collapse under fatigue after a full day. And what is safe today may not stay safe next year.

Drive control should therefore not be viewed as a single product selection. It is part of a broader system that translates human intention into reliable movement in real environments.

This guide approaches **control as architecture**, not as a product list.

Control architecture connects the person, the wheelchair electronics, the input device, and the environments in which mobility occurs. When any part of that architecture changes, performance may change as well.

The purpose of this guide is to provide clinicians with a structured framework to analyze, select, and evolve wheelchair control systems over time.

Control as access to participation

Power wheelchairs are not only about 'getting from point A to point B'. For most users, the real goal is **participation**: going to school, working, being with friends, parenting, shopping, travelling, going to events, and doing daily routines with as little dependence as possible.

Mobility enables these activities. Without reliable control of the wheelchair, participation becomes restricted.

This is why, in this guide, we treat mobility as **access to life**, not simply as a driving skill.

The World Health Organization Global Report on Assistive Technology (2022) emphasizes that assistive technology must not only be safe and effective, but also usable, maintainable, and supported by appropriate services.

In clinical practice, this translates into a simple rule:

A solution is only successful if the person can learn it, use it reliably, and continue using it in their own environment.

Therefore, it is always very important to understand what the user's goals and expectations are with and from the control (Lange & Minkel, 2025). When these goals are overlooked, dissatisfaction and device abandonment become significantly more likely.

How to use this guide

This guide provides a structured reasoning framework for control selection and optimization.

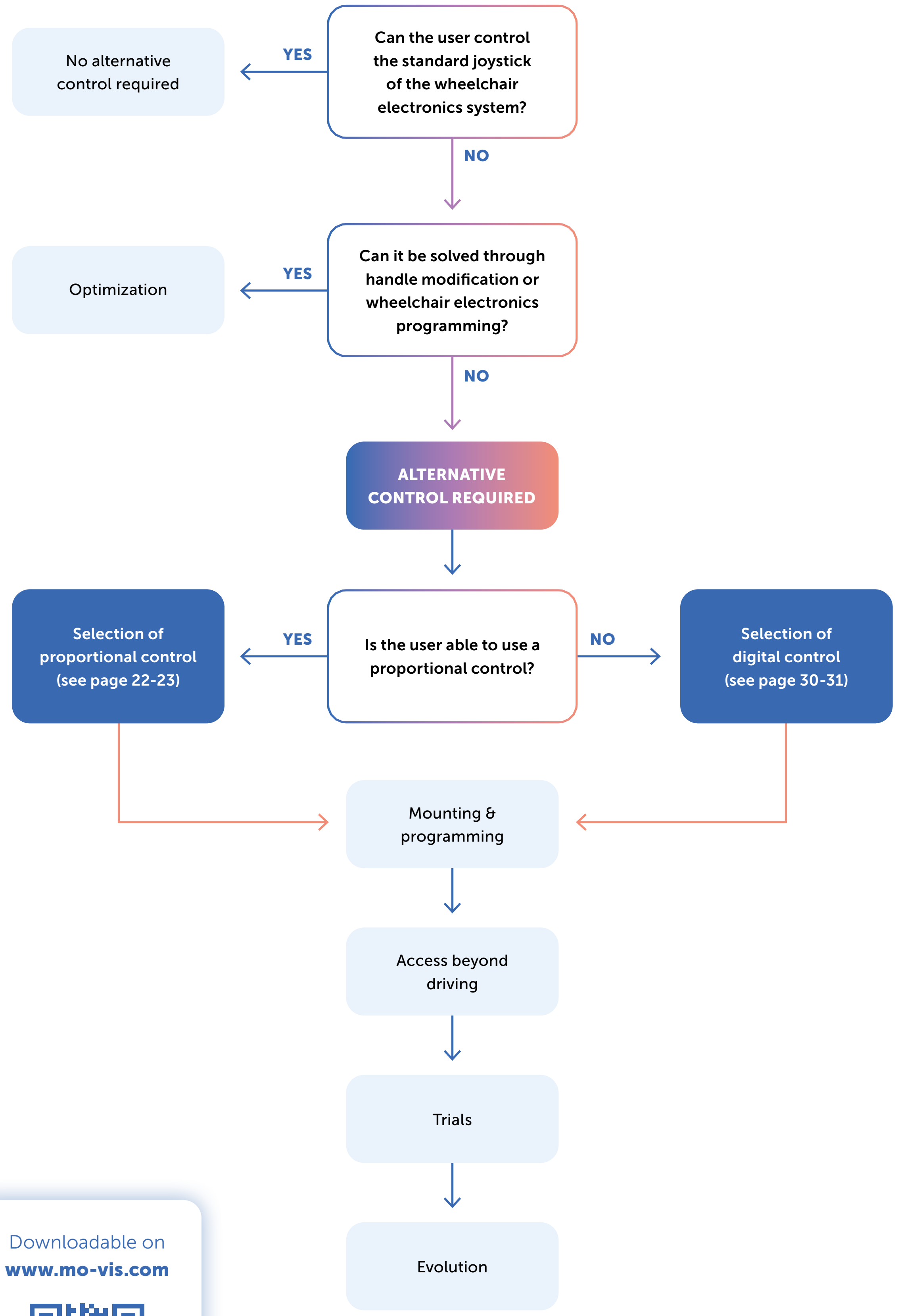
The guide is organized in five parts:

1. **Foundations**
   Explains the conceptual framework behind control architecture and the Human Technology Interface.
2. **The decision pathway**
   A step-by-step route from a standard joystick toward alternative options when needed.
3. **Architecture after selection**
   Programming, access logic, and integration beyond driving.
4. **Testing and evolution**
   Validating performance in real environments and managing control over time.
5. **Clinical justification**
   How to justify an access method and thinking ahead about complications and safety.

Throughout the guide, five key aspects shape decision-making: purpose, cognition, approach, operation and learning (each is defined in Part II). These aspects shape both assessment and long term success.

The Decision Tree as Backbone

A decision tree can organize thinking, but it should not be followed blindly. In this guide, it acts as the backbone for building a control solution that fits the person, the chair, and the environments they actually live in.



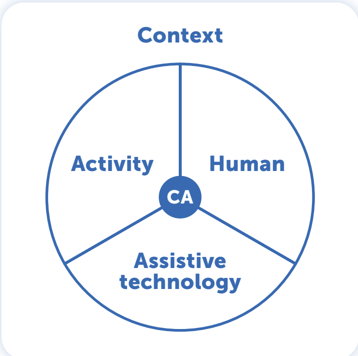
01
Foundations

Core concepts

The Human Activity Assistive Technology (HAAT) Model

Mobility is not only about driving. It is about *living*.

In the **HAAT model** (introduced by Cook & Hussey in 1995), the assistive solution is understood as the interaction between four elements:



1. **Human:** motor abilities, cognition, endurance, learning capacity
2. **Activity:** specific driving tasks and participation goals
3. **Assistive technology (AT):** wheelchair, seating, input device, programming[1]
4. **Context:** home, school, community, surfaces

Control architecture (CA) sits where these elements meet (Polgar et al., 2020). When one of these elements shifts, control performance shifts with it.

Use the HAAT model as a structured assessment tool.

1 WHO defines assistive technology as the application of organized knowledge and skills related to assistive products, including systems and services. According to WHO's definition, an assistive product is any external product, especially produced or generally available, the primary purpose of which is to maintain or improve an individual's functioning and independence, and thereby promote their well-being. (https://www.who.int/europe/health-topics/assistive-technology#tab=tab_1)

HAAT quick assessment checklist

Initial power wheelchair control assessment

User: .... Date: ....

Clinician: ....

H Human

ITEM	OK	MARGINAL	NO
Sufficient graded motor control	❑	❑	❑
Sufficient endurance	❑	❑	❑
Stable posture during driving	❑	❑	❑
Reliable return to neutral	❑	❑	❑
Adequate cognition/attention	❑	❑	❑
Able to learn new control strategies	❑	❑	❑
Motor variability manageable	❑	❑	❑

	BEST ANATOMICAL CONTROL SITE
❑	Hand
❑	Chin
❑	Head
❑	Foot

	BEST ANATOMICAL CONTROL SITE
❑	Anywhere - Switch
❑	Breath - Sip & Puff
❑	Eye gaze
❑	Other

Notes: ....

....

A Activity

	MAIN PARTICIPATION GOALS
❑	Home mobility
❑	School/work
❑	Outdoor mobility
❑	Communication/device access
❑	Independent positioning
❑	Social participation

	CRITICAL TASKS
❑	Doorways
❑	Tight turns
❑	Ramps
❑	Outdoor surfaces
❑	Crowded environments
❑	Long driving duration

Primary user goal: ....

....

AT Assistive Technology

ITEM	OK	NEEDS OPTIMIZATION	UNSUITABLE
Seating stability	❑	❑	❑
Joystick placement	❑	❑	❑
Activation force	❑	❑	❑
Throw/travel	❑	❑	❑
Mounting stability	❑	❑	❑
Current programming	❑	❑	❑

OPTIMIZATION BEFORE REPLACEMENT	
❑	Reposition joystick
❑	Midline mount
❑	Different handle/topper
❑	Reduce force/throw

OPTIMIZATION BEFORE REPLACEMENT	
❑	Programming adjustment
❑	Alternative proportional joystick
❑	Trial alternative access

C Context

MAIN ENVIRONMENTS	
❑	Home
❑	School/work
❑	Community
❑	Outdoor uneven terrain
❑	Public transport

ENVIRONMENTAL CHALLENGES	
❑	Narrow spaces
❑	Fatigue over day
❑	Crowded environments
❑	Weather exposure
❑	Long-distance driving

SUPPORT NEEDS	
❑	Caregiver support required
❑	Backup control recommended
❑	Emergency or remote stop recommended

Initial clinical impression

MOST APPROPRIATE PATHWAY	
❑	Standard joystick optimization
❑	Alternative proportional control
❑	Digital/switch access
❑	Further assessment/trial required

NEXT STEP IN DECISION PATHWAY	
❑	Optimize current setup
❑	Preserve proportional control
❑	Trial alternative proportional access
❑	Trial digital access
❑	Plan redundancy/backup strategy

Clinical notes: ....

....

The Human-Technology Interface (HTI)

The HTI is the boundary where motor intent becomes action and where feedback closes the loop: the user sends commands and the device provides feedback (Polgar et al., 2020).

In power mobility, the HTI is **where "motor intent" becomes action**:

- A direction command,
- A speed command,
- A stop command,
- Access to modes, power function, connected devices,...

For many users, the HTI extends beyond the wheelchair itself. The same input method may control seating functions, communication devices or environmental systems.

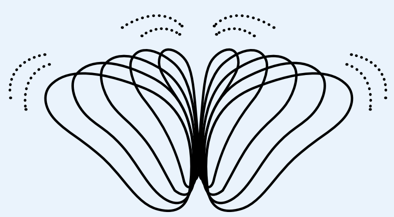
Motor intention → Input movement → Joystick interpretation → Wheelchair movement → Environmental outcome

As technology evolves, the HTI increasingly gains importance, enabling the user to move between mobility control and broader device interaction without learning entirely new control strategies. Consistency at this boundary reduces cognitive load and increases long-term sustainability.

Small mismatches at the HTI can amplify into large functional errors; therefore, the clinician's role is to minimize unintended amplification through mechanical, positional, and software strategies.

Example:

A one-millimetre unintentional joystick deviation may become a trajectory change, which in turn may become a doorway collision.



Butterfly effect:
Small movement → big impact

Five clinical dimensions for control selection

**Control selection should follow a structured reasoning process.
Five key aspects can help guide that process.**

Purpose

The first question is always: **Why is a new control system being considered?**

Motivation may include: difficulty performing basic driving tasks, fatigue during driving, inability to access seating functions, participation limitations, environmental barriers...

In other words, the **human** has an **activity** in mind in a **specific context**. How can **assistive technology**, specifically special controls, help the user to achieve this?

The benefits of powered mobility are well established. By using powered wheelchairs, people can experience increased independence, social participation and quality of life.

However, studies show that 40% of power wheelchair users experience difficulties executing basic power wheelchair tasks, such as controlling the joystick and manoeuvring backward. One of the reasons is, that there is a lack of fit between the person's abilities and his/her power wheelchair equipment (Torkia et al., 2015). Identifying the user's goals is therefore essential.

The Activities and Participation Checklist of the Wheelchair Skills Program (Kirby et al., 2016), can help to identify goals. The goal may be a full WSP skill or any other skill that is important to the user. During assessment, it has to be decided, whether the goal is feasible for the person. Sometimes this is a judgement call, but when in doubt, we should let the user try (Quellet et al., 2021).

Cognition

Each type of control has its own **cognitive demands**.

Proportional controls require continuous grading of movement but minimal sequencing. Digital systems reduce grading demand but may increase sequencing demand. Scanning systems require sustained attention and timing.

The question is not which system is simpler in general, but which system matches the user's cognitive profile.

Cognition can be a hidden limiting factor, even when motor control appears adequate.

Approach

Approach describes how the user physically reaches the control.

First, **seating stability** must be confirmed.

Pelvic alignment, trunk stability, head support, arm support, and seat-to-back angle all directly influence motor control performance. Research on seat-to-back angle and head/neck posture (Kang et al., 2021), for example, demonstrates that even small postural adjustments can significantly alter motor control capability.

If seating is unstable:

- Head control will be inconsistent
- Chin control will be fatiguing
- Joystick precision will degrade
- Switch placement may be unreliable

Always evaluate control in the context of seating and posture. A stable base is a prerequisite for reliable fine motor control.

Second, **consider which anatomical control site** gives the best control.

The interaction between the user and the powerchair involves relatively fine control. The hand and fingers are the preferred anatomical site because we typically use the hand or fingers for manipulative tasks.

If the fine motor control limitations prevent the use of the hand or even the fingers for the standard remote or any alternative hand control in multiple directions, the other anatomical sites should be explored.

Start by exploring the simplest solution. A hand joystick. If that's not possible, you look for the second simplest available solution and so on...

To have the control at an optimal position for the user, you have to be able to place it there. This might mean that you will need **mounting hardware** to place a joystick midline, mount a joystick for chin control etc. Mounting should allow repeatable alignment, adequate stability, clearance during transfers and adjustability over time.

Operation

Operation refers to the physical demands required to control the interface. We place it after approach here, but in reality it's something that is done simultaneously.

Important domains include:

- Activation force
- Range of motion
- Grading ability
- Fatigue profile
- Consistency across time

These biomechanical principles directly influence which joystick characteristics may be appropriate. For examples of different joystick characteristics, see the table on the next page with an overview of mo-vis joysticks. Besides the strength required for the control, there is also some additional **programming** that you can do to make it easier for the user. There are parameters that you can set in the electronics of the wheelchair itself, but some manufacturers of special controls also integrate specific parameters in the controls themselves.

Underutilization of these features has been described as one of the biggest obstacles still to harnessing the potential of joystick technology (Dicianno et al., 2010).

	Image	Description	Required force	Throw	Placement
Micro Joystick		A small and sensitive joystick for people with weak muscle strength.	ca. 8 g (0.28 oz.), adaptation to 5 g (0.18 oz.) possible	3.3 mm (0.13 in)	Finger, chin, tongue, lip
Multi Joystick		A multifunctional joystick controllable by various body parts.	ca. 50 g (1.76 oz.)	8 mm (0.31 in)	Finger, chin
All-round Joystick Light		A compact, lighter version of a standard joystick developed for all-round use.	ca. 120 g (0.26 lb.)	7 mm (0.28 in)	Hand, chin, attendant
All-round Joystick		A compact version of a standard joystick developed for all-round use.	ca. 250 g (0.55 lb.)	20 mm (0.79 in)	Hand, chin, attendant
Heavy Duty Joystick		A large format extremely durable proportional joystick.	ca. 650 g (1.43 lb.)	40 mm (1.57 in)	Hand

Learning

Control systems must be learnable. Some users can operate a control immediately. Others require structured practice. Training should be task-specific and aligned with the goals identified at the start. If the objective is navigating crowded spaces, then that context needs to be practiced. If endurance is the issue, fatigue states must be tested.

A standardized way to train, is of course the Wheelchair Skill Training Program (Kirby et al., 2016). The goals that you defined in the beginning with the user, the purpose, should be monitored and revised during training.

Control selection does not end at prescription. It evolves with training, context, and changes in capacity.

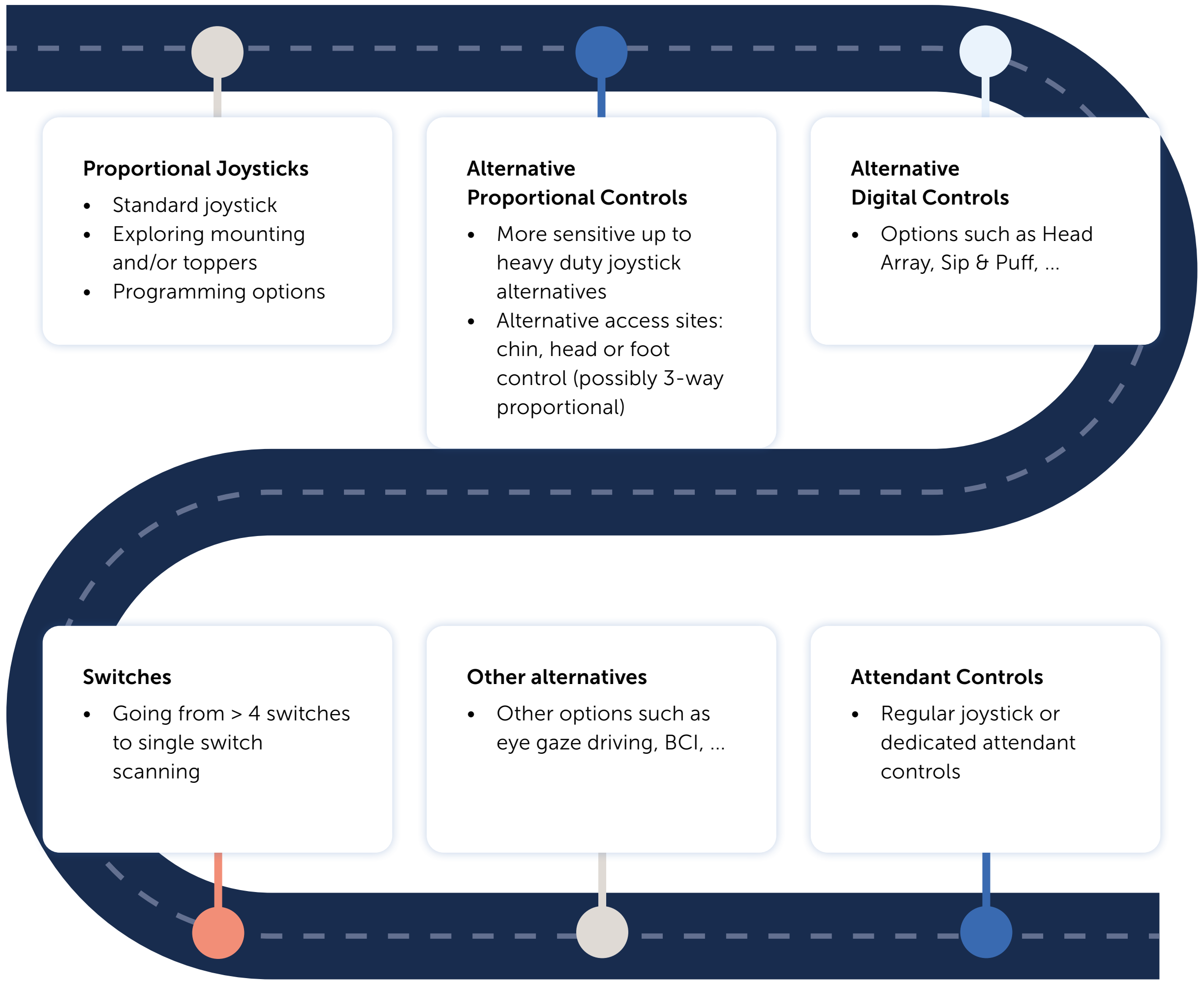
02 The decision pathway

Step 1 | Define goals & environment (participation mapping)

Begin every assessment by mapping the user's daily activities and environments. Convert participation goals into measurable trial objectives (e.g., navigate school corridor, enter public transport, perform independent transfers).

Assessment outputs: prioritized task list, environmental constraints, caregiver needs, and measurable success criteria.

Categories of drive controls



Step 2 | Can the standard joystick work?

10% of the users of power wheelchairs need individualized adaptations to their control system in order to execute activities of daily life. That means that the other 90% is using a traditional hand joystick, usually located in front of the standard armrest (Oliver & Khan, 2019). With or without display that can show you the profile or the mode you are in.

Before introducing alternative systems, the clinician must ask: Can the standard hand joystick of the wheelchair electronics system work?

A standard joystick remains the most efficient and intuitive control method for users who can operate it reliably (Lange & Minkel, 2025). It allows continuous proportional control, minimal sequencing demand, and straightforward feature access.

A standard joystick typically requires:

- Approximately 250 grams of activation force
- Sustained deflection
- Moderate joystick travel distance (20 mm)
- Stable wrist and shoulder alignment

Perhaps the standard joystick works, but not reliably during the day. Perhaps, after prolonged use, performance declines. Or it is difficult in some seating positions.
Sometimes, the user can perform most of the tasks, but needs an attendant to take over during difficult manoeuvres. Or sometimes we can already expect an evolution in capabilities.

In these cases it does not automatically justify changing the interface. It requires looking into optimization possibilities. One type of optimization can be to add an attendant control to the wheelchair. Other types of optimization are modifying the handles or adjusting the programming (see Step 3).

Screening items

ITEM	OK	MARGINAL	NO
Activation force: Can the user sustain the required force?	❑	❑	❑
Range of Motion (ROM) and throw: Can the user reach and return reliably?	❑	❑	❑
Endurance: Does performance degrade with time?	❑	❑	❑
Posture: Is pelvis and trunk stable?	❑	❑	❑
Cognition: Can the user manage continuous grading?	❑	❑	❑

Decision rule

- **If all items are OK:**
  → optimize placement and programming.
- **If marginal:**
  → structured trial with objective metrics.
- **If NO:**
  → proceed to Step 3 or Step 4.

Step 3 | Optimize before replacing

For many users, difficulty with the standard joystick develops gradually. When the standard joystick becomes physically demanding, participation decreases, even if the device remains technically usable. However, replacing too early introduces unnecessary complexity.

Handle adaptations

Small mechanical changes can significantly improve control quality.

If the user has difficulty grasping the standard joystick handle, investigate other options. Small changes can already significantly change the driving quality.

Think of:

- Custom grips (palm, fist, U-shaped) to change muscle groups used
- Toppers sized for pediatric hands or for limited ROM
- Other materials: softer, higher friction,...

Programming interventions

Programming determines how the wheelchair behaves in response to user input.
Programming should be viewed as an integral part of clinical intervention rather than a purely technical step.

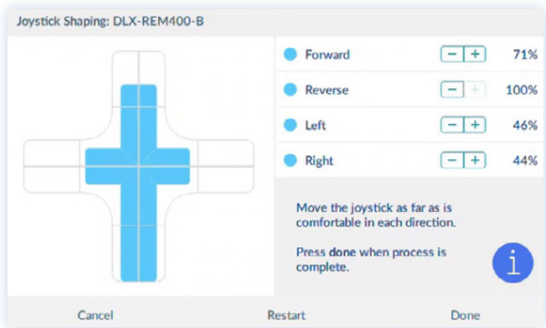
Early users often do better with slower starts, lower speeds, and predictable behavior. As skill and confidence improve, settings can be opened up step-by-step or the other way around.

In daily practice, "programming" can mean **two different things**:

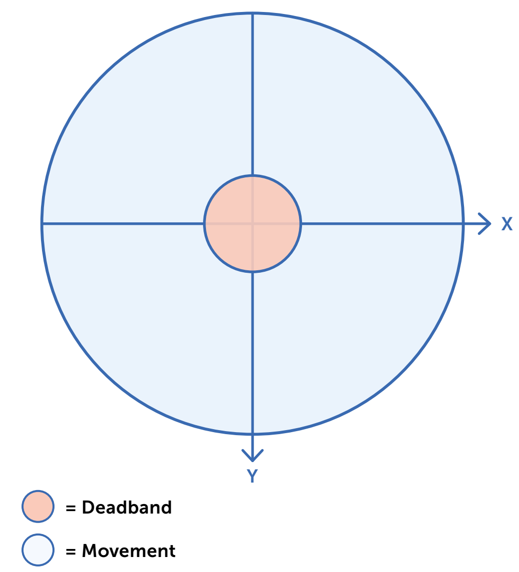
1. Wheelchair (OEM) drive settings:

Settings inside the wheelchair electronics that shape how the chair drives. These are typically adjusted with the OEM's programming tools. A few examples:

- **Speed, acceleration and deceleration:** Slow starts reduce startle and tone escalation; deceleration can be tuned to avoid long stopping distances. Programming of these parameters should reflect a combination of motor profile, environment and user confidence.
- **Throw:** Reduce mechanical travel or use electronic mapping to reduce required movement. Here you see an example of joystick shaping (throw mapping) in the LiNX Configurator. At 71% deflection forward, the user will reach 100% of speed.



- **Deadband:** the neutral zone around the center position where small movements are ignored. It is one of the most influential yet frequently overlooked parameters. If deadband is too small, minor tremor or tone-related fluctuations may unintentionally activate movement. The user may describe the chair as "too sensitive" or unpredictable. In contrast, if deadband is too large, the user must move further before activation occurs. This can increase fatigue and reduce the usefulness of small, controlled movements.
  For users with essential tremor, cerebral palsy, dystonia, or other involuntary movement patterns, tremor filtering or sensitivity adjustment can reduce unintended micro-activations.



- **Different profiles:** Many control systems allow multiple drive profiles. Profiles can vary in maximum speed, acceleration, sensitivity, and filtering parameters. This allows the same mechanical interface to function differently depending on context. An indoor profile may prioritize reduced maximum speed, lower acceleration, and slightly increased deadband for safety in confined spaces. An outdoor profile may allow higher maximum speed and more responsive behavior to navigate longer distances efficiently.

2. Input device settings:

Settings inside the input device or its configuration workflow (road compensation, overload force compensation, tilt sensor). These are configured using mo-vis tools when mo-vis controls are part of the setup.

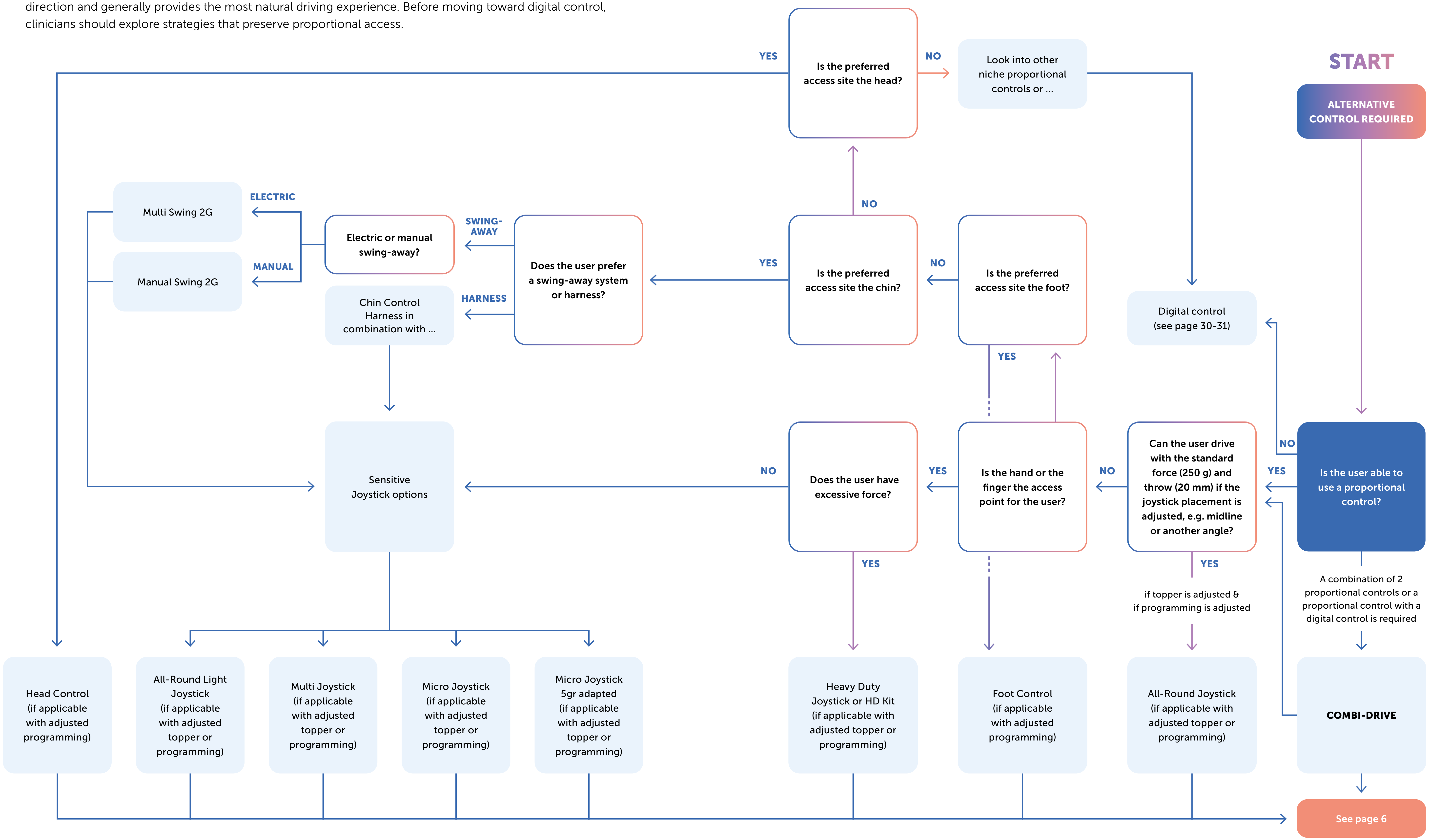
At mo-vis, we developed the 'Road Compensation', which is part of all our joysticks. An accelerometer inside the joysticks can sense when the driver is on an uneven road, automatically adjusting the speed of the wheelchair for the user to allow for safe and easy driving. Another example is 'Overload force detection' in the mo-vis Head Control. The device can filter out excessive force or spastic movements to avoid unwanted driving actions.

When to transition

Transition to alternative controls is indicated when optimization no longer produces reliable control. Indicators may include: inability to consistently return to neutral, excessive fatigue, tone-related overshoot, unsafe trajectory control. In some cases, transitions occur because abilities decline. In other cases, they occur because skills improve and allow more advanced control strategies.

Step 4 | Alternative proportional control

When optimization is insufficient, alternative controls may be required. The next clinical question is whether **proportional control can still be preserved**. Proportional control allows continuous grading of speed and direction and generally provides the most natural driving experience. Before moving toward digital control, clinicians should explore strategies that preserve proportional access.



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Standard joystick placement

Mounting location significantly influences endurance and control quality. The typical standard armrest-end position works well for many users. It aligns naturally with the forearm and does not interfere with transfers. However, even small deviations in angle or distance can increase shoulder strain and reduce precision over time.

A stand-alone or repositioned joystick can correct these subtle mismatches. Midline placement can also often be useful to reduce shoulder strain, improve symmetry, and decrease compensatory movement patterns. In progressive neuromuscular conditions, reducing reach distance may meaningfully extend independent use. However, when placed in such positions, it needs to be taken into account that the joystick needs to be put away during transfer. Sometimes the user can press a switch to swing the joystick away.

Alternatives for hand or finger access

Users with excessive force could benefit from a **Heavy Duty Joystick**. These joysticks require more grams of force (e.g. 650 gr compared to 250 gr) and have a larger throw. This way, they are better suited to withstand large and forceful movements.

For users with excessive tone or force, increasing joystick resistance can improve control stability. A wheelchair user with strong involuntary movements repeatedly overloaded standard joystick modules, causing erratic driving and device wear.

A high-resistance joystick requiring greater activation force stabilized control and better matched the user's movement characteristics.

Reducing required activation force is another effective intervention. Mini proportional joysticks typically require significantly less force than standard joysticks. While exact specifications vary by manufacturer, the reduction can be clinically meaningful for users with weakness or fatigue. Lower activation force can reduce fatigue, decrease pain, improve precision, extend daily driving duration, and prolong independent mobility in progressive conditions.

Even if the hand function is limited, the joystick can accommodate for limitations in fine motor control through adaptations of the joystick handles. A different shape can mean a difference in which muscles, extensors and flexors you need.

Another way to preserve function for sensitive joysticks, is placing a **Hand Warmer** in front of the device. Some people have some control over their fingers and hands, but encounter problems when the fingers or hands get cold and stiff. The already very reduced movement capabilities become more difficult or even impossible. A Hand Warmer can help in that case, as it blows warm air on the fingers, so the finger flexibility is maintained. Domes can be used to keep the warm air longer around the hands and protect the hands and fingers from rain and cold.

Reducing activation force can prolong independent proportional driving in progressive neuromuscular conditions. A wheelchair user with progressive muscle weakness gradually lost the ability to sustain the activation force required for a standard joystick. Switching to an ultra-sensitive joystick with significantly lower activation force allowed the user to maintain proportional control without changing the overall driving strategy.

Alternative access sites

If the fine motor control limitations prevent the use of the hand or even the fingers for the standard remote or any alternative hand control in multiple directions, the use of other anatomic sites need to be explored.

Each option introduces different biomechanical considerations and must be evaluated carefully.

Foot Control

A possible control site where multiple movement is possible, but not used very frequently, is foot movement. For driving a powerchair, the foot is less desirable because there is no visual monitoring and the foot is generally not as finely controlled as the hand. However, some individuals are able to develop good control. This is sometimes the case in people with Cerebral Palsy and movement disorders such as dystonia or athetosis. It can also be seen in people with ALS.

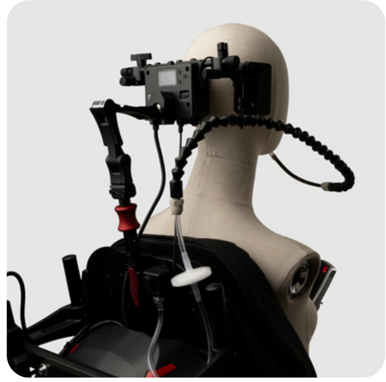
A wheelchair user with strong lower-limb control but limited hand function required an alternative input method. Driving was achieved using foot control, allowing precise directional movement and enabling participation in adaptive sports.

Head Control

The head as an anatomical site is also an option, because multiple movements are generally preserved and it is often possible to obtain relatively precise control using head movements such as tilting side to side, rotation, or forward and backward movements. Head control can therefore provide proportional and continuous wheelchair driving for individuals with limited or no functional use of the upper limbs, such as people with high cervical spinal cord injury, muscular dystrophy, or advanced neuromuscular disorders like ALS.

Proportional head control systems typically use sensors integrated into the headrest to translate head movements into smooth directional and speed commands. Proper positioning and installation are essential to ensure stable and reliable control throughout the day. Although head control preserves intuitive driving and graded speed control, it may also introduce challenges such as cervical fatigue, reduced precision on uneven terrain, or unintended activations caused by involuntary movements or fluctuating muscle tone.

A sip and puff system can be added to the system when needed and if the user has good oral control.



Chin Control

Another option for control using the head region is chin (or even lip/tongue control). This may be appropriate in high cervical spinal cord injury, ALS with preserved cervical strength, or severe upper limb weakness. Chin control preserves graded speed and continuous directional control, avoiding the stepwise logic of digital systems while still allowing precise wheelchair driving.

To position the control in front of the user, different mounting solutions can be used. A harness system moves along with the user throughout the day, helping to maintain a consistent position relative to the chin even when posture changes. Another option is a manual or motorized swing-away arm or chin boom, which can move horizontally or vertically depending on user preference. Stable installation is essential to ensure reliable control.

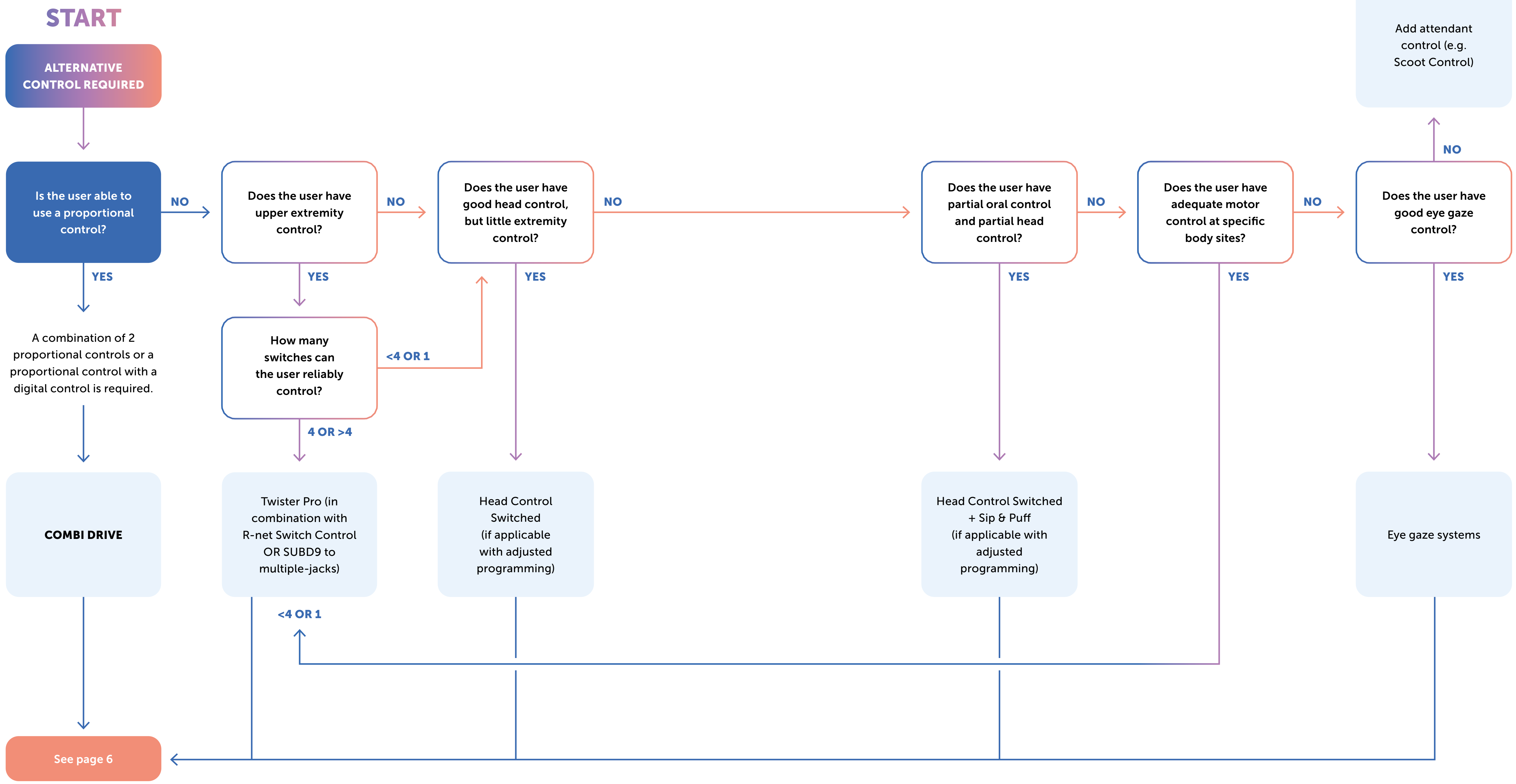
Motorized systems can further improve independence by allowing the user to move the control away from the face independently and may also support programmable functions such as wheelchair actions or environmental controls. Potential challenges of chin control include temporomandibular strain, cervical fatigue, and reduced stability on uneven terrain.

Step 5 | When proportional control is not sustainable

Using a joystick looks easy, but it's not. Users who cannot grade the force and distance of their movement may require a non-proportional (i.e. digital) driving method. The same goes for users with cognitive limitations who cannot grasp the link between the movement of the joystick and the speed of the chair. Digital control separates commands such as forward, left, right and stop into individual activations. This approach reduces grading requirements but may increase sequencing demands.

Cognitive demand depends on *what makes control hard for the user*:

- Some users find digital easier, because the commands are **clear and separated**
- Other users find digital harder because it can require **more steps** to achieve the same



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Upper-extremity control

Switch systems allow directional control using discrete activations. Switches may be mounted on trays, arm supports, or other accessible locations.

With three switches you can already control forward, left and right. If a fourth switch is possible, you can also program reverse driving or mode. The forward switch is to be placed at the 'best' location, as it requires best control. The mode switch is lowest on that hierarchy.

If less than four switches are possible, it may be worth looking into other digital alternatives.

The choice of switch is also important. Light-activation switches such as 30 g Twister buttons may suit users with minimal force output, whereas medium-force switches (e.g., Twister Pro with 75 g) may improve stability and reduce unintended activation.

Head Arrays

Head arrays allow directional control through head movement. They are typically considered when upper-limb control is absent or inconsistent, but head control is available.

However, these systems are sensitive to posture and seating position. Common challenges include cervical fatigue, tone variability, sensitivity tuning requirements, and changes in head positioning across tilt and recline.

This is where a key principle returns: positioning changes affect control. A head system that works upright may behave differently in tilt, recline, or after prolonged use (Kang et al., 2021).

Test head systems across multiple seating positions and over sustained time — not only upright and not only for five minutes.

From multiple to single switch scanning

Sometimes the user does not have best control at the 'traditional' access sites or at sites scattered across the body. These sites must be identified and switches must be placed there.

When there is only one switch site possible, the user can try single-switch scanning. Directional (and potentially other) options are scanned, which the user can activate with the switch. There's a lot of individual programming that can be done for single-switch scanning (type of scanning, speed of scanning,..)

Scanning-based driving is typically considered when:

- Only one reliable motor site exists
- Multi-direction discrete activation is not feasible
- The user has sufficient cognitive endurance for sustained attention and timing tasks

Scanning requires sustained attention, timing precision, sequencing, and inhibition control. It is often slower and can be cognitively demanding. Lange and Minkel (2025) describe scanning as inherently less efficient than proportional control and typically more demanding to use.

Single-switch scanning is usually a last-resort driving pathway when only one reliable activation site exists. It should only be selected after more efficient and less demanding options have been ruled out, and it must be validated in real-life trials.

Eye gaze as alternative access

Eye gaze can be appropriate when:

- Upper limb function is absent
- Head control is insufficient or unreliable
- Cognition is sufficient to support sustained attention
- Visual control is stable

Research supports feasibility. A study by Elliott et al. (2019), for example, on eye-controlled power wheelchair use in ALS reported feasibility and positive user experience in appropriate cases.

However, eye gaze introduces distinct demands:

- High sustained visual attention
- Environmental dependence (lighting, calibration, visual interruptions)
- Potential reduction in precision in constrained environments
- Fatigue effects over time

Maule et al. (2023) showed that gaze-based driving can be viable, but joystick control performed better in narrow doorway contexts.

Eye gaze is a powerful option for users who need it, but it should not be assumed superior to optimized proportional control when proportional remains feasible.

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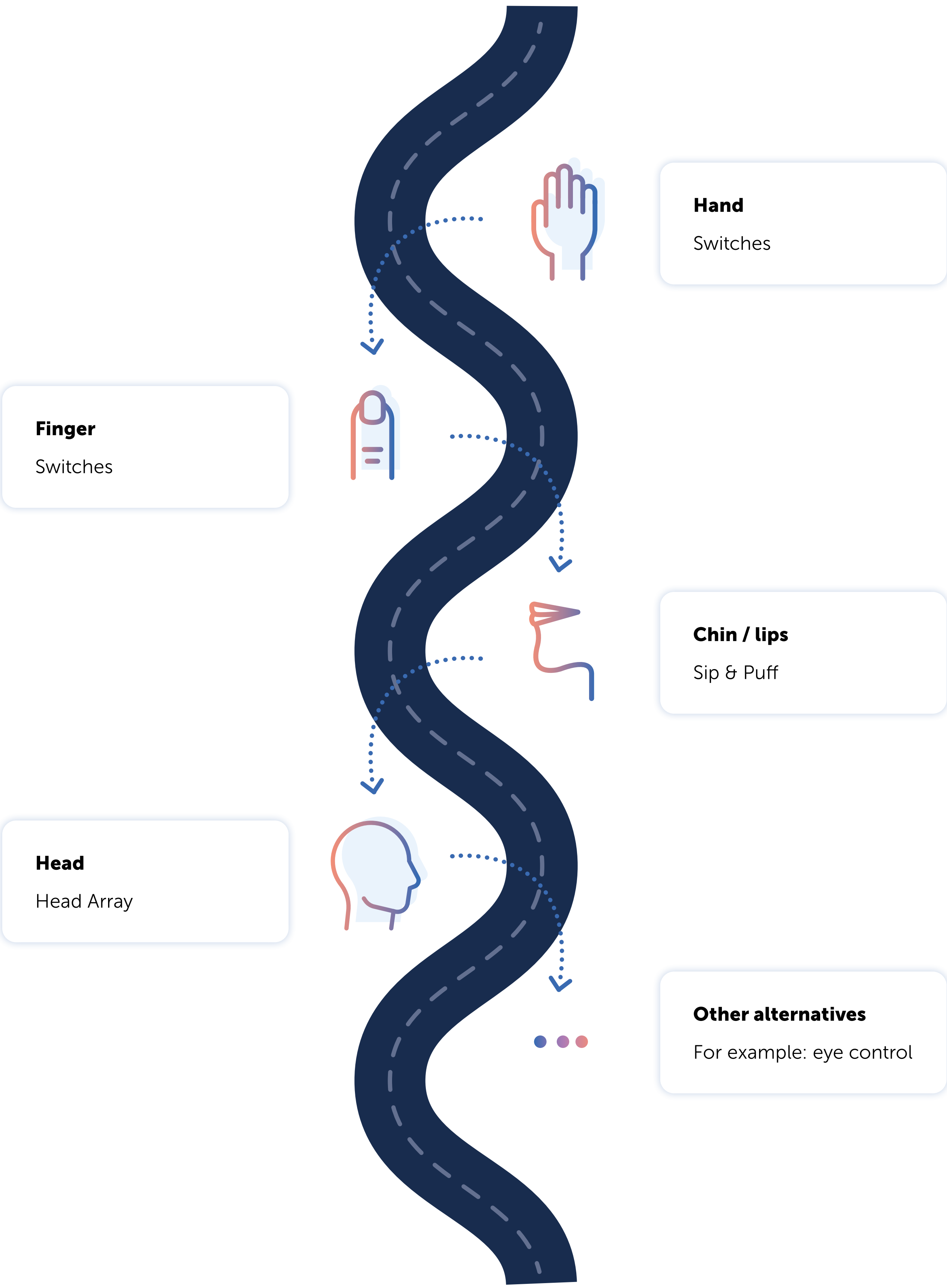
Digital controls



Step 6 | Alternative mobility strategies and attendant solutions

There are situations in which independent control cannot be achieved safely. This may occur when no reliable motor site is available, cognitive demands exceed user capacity or safety cannot be ensured despite careful adjustments. In these cases, alternative mobility pathways must be considered.

Attendant Control

Attendant control allows caregivers to operate the wheelchair.

For some users, particularly those with profound motor impairment or severe cognitive limitation, independence in driving may not be realistic. Attempting to force independence in such cases can increase anxiety, risk and caregiver burden. It is also a must to consider attendant control for people with progressive conditions.

The focus should then shift from autonomy in driving to safe mobility.

It is possible though, that the user can still manage their seating positions or environment through the wheelchair, even though driving isn't safe anymore. This is still very valuable, as the user can independently take care of their comfort, skin integrity, infrared and Bluetooth connections etc… (Lange & Minkel, 2025)

Multimodality

Multimodal control means using two input methods on purpose as part of normal operation (for example: combining switch input with proportional input, or combining two proportional sources). The goal is improved performance, reduced fatigue, or better stability. Fager et al. (2022) suggest that combining inputs (for example, gaze plus switch scanning) can improve robustness compared to relying on a single method.

Until recently, most power wheelchair systems required a single active input pathway at a time. Switching between proportional, digital, or alternative inputs typically required manual reconfiguration or complete mode changes, limiting true multimodal control. Newer wheelchair control architectures are beginning to support more flexible combinations of input methods, allowing clinicians to combine motor domains in a more structured and individualized way.

This may be clinically relevant when a primary proportional method remains mostly reliable but fatigue or variability requires a secondary stabilizing input, when two motor domains can be combined to improve precision or reduce physical load, or when a progressive condition requires gradual transition from one control strategy to another.

Multimodal systems should not replace proportional control prematurely. Instead, they may become valuable when motor variability, fatigue, or disease progression suggests that a single input pathway is becoming limiting.

Redundancy planning

While multimodality aims to improve performance, redundancy aims to prevent loss of control.

Redundancy means having a **backup pathway** available when the primary method becomes unreliable (fatigue, tone changes, progression, environment). Redundancy is about safety and continuity.

A backup switch, an emergency stop, an alternative input pathway, or a secondary drive profile adapted for fatigue can provide continuity when the primary method becomes unreliable.

This is particularly important in progressive neuromuscular conditions, severe motor variability, or situations where emergency control must be guaranteed.

Planning redundancy early allows transitions to occur calmly and predictably rather than during crisis.

Primary proportional control → Fatigue detected → Secondary input activated → Driving continuity preserved

03
Architecture after selection

Access beyond driving

Selecting a control method is only the beginning. Long-term success depends on how that control is integrated into daily activities, seating access, environmental interaction and future adapation.

Mobility is only one domain of participation. In contemporary power mobility, the control system increasingly functions as access infrastructure, not only for driving, but also for seating functions and, in many cases, digital interaction.

Control architecture must therefore support multiple domains without fragmenting the user experience.

These domains typically include:

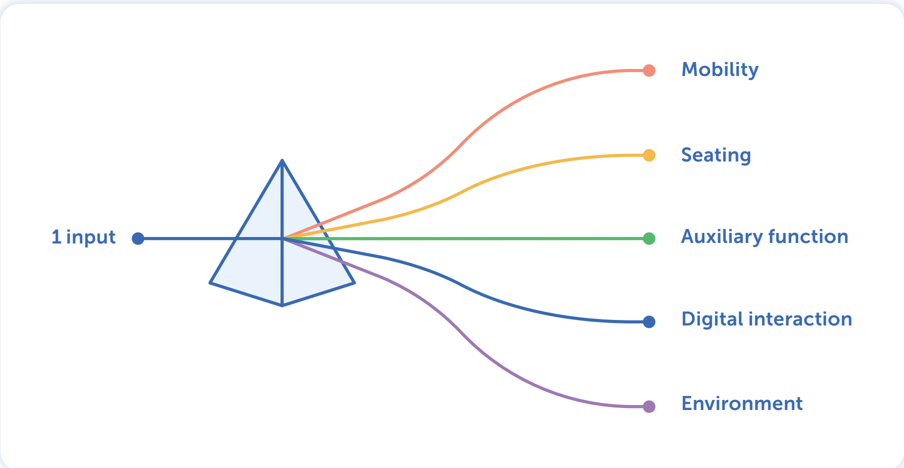
1. **Mobility:**
   Driving and directional control
2. **Seating & auxiliary functions:**
   Tilt, recline, elevation, speed profiles
3. **Digital & environmental interaction:**
   Communication devices, smartphone/tablet access, environmental control systems

When these domains are managed through unrelated logic or inconsistent interfaces, cognitive burden increases and independence may decrease.

Three domains, one access pathway

A well-designed control architecture recognizes that a single input pathway may serve multiple domains. The objective is to keep frequently used functions easy to access while maintaining clear separation between driving and non-driving modes.

The more frequently a function is used, the simpler its access pathway should be. High-frequency tasks (driving, tilt) must require fewer steps than low-frequency tasks. If medically necessary features are difficult to access, they will not be used consistently. A study by Ward et al. (2025) demonstrated increased use of power seating features when access pathways were clarified and supported for users with ALS, for example.



Minimal access architecture

Minimal access architecture refers to a control philosophy in which the number of required physical inputs is intentionally minimized while preserving full functional access to wheelchair driving, seating, communication, and environmental control.

This approach is especially important when only one reliable motor site is available, when fatigue limits switch use, or when a progressive condition reduces motor function over time.

Rather than adding more buttons or switches, you focus on maximizing the functional value of a small number of reliable inputs.

Configurable modules such as Multi Switch, R-net Switch, Multi Swing 2G or the Actuator Keypad (Pro) allow a single switch or limited set of inputs to control multiple functions, such as

- wheelchair driving,
- seating adjustments,
- actuator control,
- smartphone or computer access,
- communication software,
- and environmental control systems.

Customizable switch arrays, such as the R-net Switch module, allow frequently used functions to remain directly accessible without entering deep menu structures. Triple-action programmability and flexible assignments help optimize access efficiency while reducing physical effort.

Essential functions generally include:

- a reliable on/off control,
- mode selection,
- and access to safety-critical functions.

Alternative strategies may include gesture-based control, timed selection, scanning systems, standby selection, ...

The goal is not to maximize the number of available functions, but to maximize practical usability with the lowest sustainable physical and cognitive effort while maintaining long-term access stability.

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Compatibility with wheelchair electronics

Alternative drive controls do not operate in isolation. They must function within the electronic architecture of the power wheelchair.

Complex rehabilitation wheelchairs typically rely on wheelchair electronics that manage driving, seating functions, environmental control, and communication interfaces. For clinicians and users, it is essential that alternative control solutions remain compatible with these systems (Lange & Minkel, 2025).

A control interface should not restrict the choice of wheelchair electronics. The user should be able to combine the most appropriate drive control with the most appropriate wheelchair platform.

For this reason, many special control manufacturers design their devices to interface with the major expandable wheelchair electronics ecosystems. Maintaining compatibility across platforms allows clinicians to focus on functional matching rather than system limitations.

For example, mo-vis devices are designed to be compatible with R-net, LiNX and Curtis electronics. This approach allows the same control philosophy to be implemented across different wheelchair systems without forcing users into a specific manufacturer ecosystem.

Compatibility therefore becomes part of good control architecture. It preserves clinical flexibility and protects long-term adaptability for the user.

04 Testing, validation and lifecycle

Trial design that predicts real life

A control method can look successful in a clinic and still fail in daily life. Clinic trials often happen in conditions that are unusually supportive: quiet rooms, smooth floors, short durations, and minimal distraction. Real life is different. Users must manage narrow corridors, ramps and thresholds, busy spaces, uneven surfaces, fatigue, and divided attention.

A five-minute successful trial does not predict real-world success.

Trial protocol essentials

- **Duration:** minimum of twenty minutes of continuous use across at least two days to capture fatigue effects.
- **Various settings and circumstances:** include tasks that reflect the user's real environment, such as narrow doorway passages, tight turning in hallways, ramp ascent and descent, crowded spaces... Do not limit trials to driving performance. Feature navigation often determines whether medically necessary functions are used. Trials should include tilt and recline, returning to drive, switching speed profiles, entering and exiting (digital) modes,...
- **Metrics:** use metrics such as overshoot events, number of interventions, subjective fatigue and user confidence.
- **Reporting:** standardized trial report with objective data and clinician recommendations. Summarize findings in a structured way.

Example statements:

- Proportional mini interface with increased deadband and reduced acceleration maintained stable control across extended trial, narrow doorway tasks, and distraction. Digital transition is not indicated at this time.
- Despite optimized programming, proportional input became inconsistent under fatigue and distraction with unsafe overshoot. Digital directional control provided predictable input during environmental testing.

Trial report template

User information

User name	
Date of birth	
Diagnosis / relevant medical condition	
Current equipment	
Equipment on trial	
Clinicial / therapist	
Caregiver(s) present	
Trial location	
Date & duration of trial	

Trial goals

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Tasks and environments evaluated

TASK	ENVIRONMENT	COMPLETED INDEPENDENTLY	ASSISTANCE REQUIRED
Wheelchair driving	Indoor / Outdoor	Yes / No	None / Minimal / Moderate / Full
Wheelchair turning	Wide / Narrow	Yes / No	None / Minimal / Moderate / Full
Wheelchair ramps	Ascent / Descent	Yes / No	None / Minimal / Moderate / Full
Wheelchair transfer	/	Yes / No	None / Minimal / Moderate / Full
Environmental control	/	Yes / No	None / Minimal / Moderate / Full
Seating adjustments	Home / School / Other	Yes / No	None / Minimal / Moderate / Full
Computer or phone access	Home / School / Other	Yes / No	None / Minimal / Moderate / Full

Additional observations: ....

....

Objective trial metrics

METRIC	OBSERVATION
Number of failed activations	
Number of accidental activations	
Interventions required	
Observed fatique	Low / Moderate / High
Observed confidence	Low / Moderate / High
Consistency of access	Poor / Fair / Good / Excellent

Additional objective notes: ....

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Subjective feedback

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Clinical recommendation

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	YES	NO
Additional training required	❑	❑
Follow-up needed	❑	❑

Next steps

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Evolution over time

Control architecture is often treated as a single prescription event. In reality, it is dynamic. A control solution that is safe and efficient today may become limiting or unsafe over time. Control architecture should therefore be viewed as a lifecycle strategy rather than a static decision. Whether adapting to progression, growth, or environmental change, architecture should aim to preserve familiarity. When input methods evolve, interaction patterns and navigation logic should remain as stable as possible. Reducing the need for relearning supports confidence, autonomy, and long-term adherence.

Progressive conditions

In progressive conditions such as Amyotrophic Lateral Sclerosis (ALS), Duchenne Muscular Dystrophy (DMD), and Spinal Muscular Atrophy (SMA), motor capacity does not remain stable. Control decisions in progressive diagnoses should therefore prioritize reducing physical effort, preserving proportional control as long as safe, planning adaptation before failure and optimal placement to reduce reach and shoulder load

Motor variability

In cerebral palsy, particularly dyskinetic or dystonic presentations, the primary issue is not decline but variability. Challenges include involuntary movement, overshoot, oscillation, and inconsistent return to neutral. The problem is not insufficient force but inconsistent force modulation. Some users experience day-to-day variability, fluctuating tone, variable endurance, and position-dependent performance. Profile adjustments, repeatable mounting, simplified mode logic, and alternative access options can stabilize performance across fluctuating states. Responsiveness may need to be sacrificed slightly to gain predictability.

Pediatrics and Development

RESNA (2018) supports early introduction of power mobility when developmentally appropriate. A 2023 study on early power mobility in children with Fukuyama congenital muscular dystrophy demonstrated clear improvements in participation and engagement *(Fujita, 2023).*

Early power mobility supports agency, exploration, and cognitive development.

Control should evolve in stages:

1. **Stage 1 – Stability First**
   Low speed, predictable start/stop, simplified access.

2. **Stage 2 – Controlled Expansion**
   Gradual increase in speed and responsiveness as skill improves.

3. **Stage 3 – Functional Expansion**
   Introduce additional functions only when driving is reliable and safe. Children require predictability before complexity. Mounting and interface placement must accommodate growth, seating evolution, and changing postural needs. Architecture should allow expansion rather than require redesign.

Redundancy and safety planning

Redundancy is part of good architecture. A secondary access pathway, an attendant control, or an emergency stop may never be used. Its presence, however, changes the safety landscape.

Redundancy is particularly important when performance fluctuates unpredictably, when decline is documented during extended trials, or when control depends on a single fragile motor site. Planning redundancy early prevents crisis-driven decisions.

Reassessment, documentation and service pathways

Documentation should use standardized language that links every programming or hardware adjustment to a clear clinical rationale. Parameter changes such as sensitivity, acceleration, deadband, switch timing, or seating actuator access should be recorded together with the observed problem, intended goal, and resulting outcome. This improves continuity between clinicians, suppliers, technicians, and funding bodies, while also supporting troubleshooting and future reassessment. Consistent documentation becomes particularly important when multiple professionals are involved across different service stages.

Service pathways should also define responsibilities explicitly. The clinical team should determine functional goals, assess access methods, and evaluate safety and performance. Technical programming may be performed by trained suppliers, rehabilitation engineers, or specialized technicians depending on local service models. User and caregiver training responsibilities should likewise be identified clearly, including who provides initial instruction, environmental practice, and follow-up support. Without defined ownership, important adjustments or safety concerns may remain unresolved.

A structured reassessment schedule is recommended during the first year after provision. Initial follow-up commonly occurs within the first few weeks to address setup issues and optimize parameters after real-world use. Additional reassessment at approximately 3 months, 6 months, and 12 months allows evaluation of fatigue, accuracy, posture, access consistency, skin integrity, and environmental performance. Earlier review should be triggered whenever significant functional changes occur, including increased falls or collisions, rising fatigue, pain, reduced driving endurance, inconsistent switch access, progressive weakness, cognitive changes, seating modifications, or visible device wear and mounting instability.

Reassessment should focus not only on whether the user can still operate the system, but whether the current configuration remains the most efficient, safe, and sustainable solution for daily participation.

Documentation

- Problem
- Goal
- Outcome
- Programming & hardware adjustments

Service

Define responsibilities:

- Clinical
- Technical
- Caregiver
- User

Reassessment

- Initial follow-up
- Reassessment after planned intervals
- Earlier review if necessary

05 Clinical justification

User-specific and functional outcome-oriented justification

Clinical justification should focus on the specific driving limitations observed during assessment and how the selected configuration improves functional mobility in daily use. It should explain why the selected options are medically necessary to achieve safe and sustainable participation driving skills.

Justifying an access method

Build a strong clinical justification. Check (☑) the items that apply to your user. Use the summary and conclusion boxes to build your rationale. Tip: You don't need to use all items. Select the most relevant ones and tailor your rationale to the individual.

1 What limits driving performance?

Select **the factors** that are relevant for your user.

❑	Reduced steering accuracy
❑	Inconsistent switch activation
❑	Fatigue during prolonged driving
❑	Limited endurance
❑	Poor access stability
❑	Excessive cognitive effort
❑	Declining performance over time

2 How does this affect daily mobility?

Select **the impacts** that apply to your user.

❑	Difficulty traveling independently
❑	Avoids going to certain places
❑	Needs more time to complete tasks
❑	Reduced participation in school, work or community
❑	Needs frequent caregiver assistance
❑	Increased physical and cognitive effort
❑	Lower endurance throughout the day
❑	Safety risks in complex environments

③ Why is the proposed access method the most effective and sustainable option?

Select **the reasons** that support your choice.

❑	Matches user's residual abilities
❑	Provides more consistent control
❑	Reduces physical and cognitive effort
❑	Improves accuracy and control
❑	Supports longer and safer use
❑	Adapts to progression over time
❑	Minimizes setup and maintenance
❑	Cost-effective and scalable
❑	Evidence-based / proven effectiveness

④ Practical outcomes (what does this achieve?)

Select **the expected outcomes** for the user.

❑	Improved independent mobility
❑	Reduced caregiver assistance
❑	Better access in school, work or community environments
❑	Improved endurance throughout the day
❑	Safer operation in complex environments
❑	Increased confidence and participation
❑	Better quality of life

Notes: ....

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① Limits driving performance

Your rationale summary:

- ....
- ....
- ....
- ....

↓

② Affects daily mobility

Your rationale summary:

- ....
- ....
- ....
- ....

↓

③ Why this access method is best

Your rationale summary:

- ....
- ....
- ....
- ....

↓

④ Expected practical outcomes

Your rationale summary:

- ....
- ....
- ....
- ....

Prevention of Complications and Safety

Specialized access is often justified not only by improved function, but by reduction of safety risk and long-term complications.

Relevant considerations may include:

- increased collisions or near misses,
- fatigue-related deterioration,
- pain or overuse,
- unstable posture during driving,
- inconsistent access to stop functions,
- increasing caregiver intervention,
- or reduced driving reliability in busy environments

The interaction between access method and seating should also be considered. Some users compensate with excessive trunk movement, asymmetrical posture, or sustained effort to maintain control access. Over time, this may reduce endurance and affect positioning tolerance.

For users with progressive or fluctuating conditions, stability and consistency may be more important than maximal short-term performance. Configurations that allow gradual adaptation or multimodal access may reduce future service disruption and help maintain independent mobility longer. Clinical justification should ultimately explain why the selected configuration represents the safest, most reliable, and most sustainable driving solution for the user's daily environments.

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