The CCK

CLERESTORY



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Three things to remember about stroke

1. **Know the signs of stroke.** Watch for sudden facial drooping, weakness in one arm, or trouble speaking or understanding speech. Other signs include sudden changes in vision, loss of balance, numbness on one side of the body, or a sudden, severe headache.
2. **CALL 9-1-1 IMMEDIATELY** if you or someone else has any of these signs, even if the symptoms go away.
3. **Check your blood pressure regularly.** If it's high, talk to your doctor about how to manage it.

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Table of Contents

Editor's Note 2

Don't Panic 3

Stroke: An Experience Between Science and Life 11

From Emergency Call to Hospital Arrival 15

Unfolded Brain Connections 21

Grip Strength Recovery After Stroke 23

After Nine Years, She Opened Her Hand Again 28

Oxygen Supply, Stroke, and Neuronal Survival 29

When Brain Cells Fall Silent 32

Decompressive Craniectomy & Intracranial Pressure 33

Blood Pressure 37

Statistical Analysis of Stroke Data Based on the Weibull Distribution 39

Dear Reader,

The fourth issue of *The CCK CLERESTORY* focuses on stroke. Through this theme, we connect ideas from mathematics, physics, and biology with emergency care, rehabilitation, and the lives of people affected by stroke.

The issue begins with Jean-Dominique Bauby, who dictated his book by blinking his left eye to select letters. His method leads to a question about how the order of those letters affects the time needed to communicate. A fictional story then follows a neurologist who experiences stroke symptoms himself and tries to understand them as both a doctor and a patient.

An ambulance journey provides a setting for studying motion and delay. The central spread presents an unfolded view of brain connections using a Mercator transformation. Weekly measurements of grip strength then help us examine rates of change during rehabilitation.

A feature on experimental electrical stimulation describes how it can assist hand movement after stroke.

Problems on oxygen supply to the brain are followed by a short introduction to the ischemic penumbra. A problem on decompressive craniectomy explores the relationship between blood pressure and pressure inside the skull, alongside historical notes on surgery.

Because managing high blood pressure is important in stroke prevention, we then review what blood pressure is and how it is measured. Finally, using Canadian stroke data, readers examine how reported cases are distributed across age groups and how well a mathematical model describes that distribution.

Our aim is to connect classroom learning with questions about stroke through educational problems. Some situations and models are simplified to make the ideas easier to study.

For specialist information or advice on prevention, diagnosis, treatment, or rehabilitation, readers should consult qualified healthcare professionals and trusted medical sources.

Sincerely,

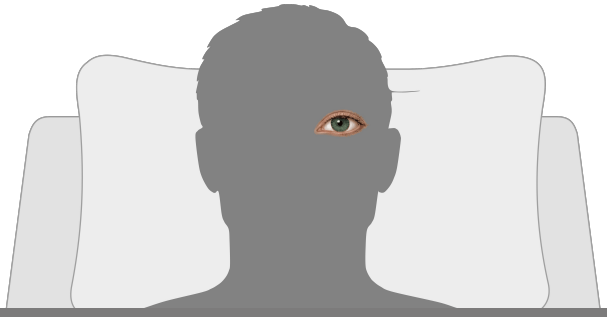
Dr. Kamal Shahtalebi

Editor-in-Chief



Don’t Panic

Decoding Thought, One Blink at a Time



In the summer of 1996, Jean-Dominique Bauby began dictating his memoir, *Le Scaphandre et le Papillon*, known in English as *The Diving Bell and the Butterfly*, to Claude Mendibil. The stroke had left him with only one voluntary movement, a blink of his left eye, and he used it to communicate. Claude read the letters aloud, and Jean-Dominique blinked when she reached the one he wanted.

At first, Claude found it difficult to follow the letters while watching for his signal. Jean-Dominique noticed. He used his first words to reassure the woman who had come to help him write. Letter by letter, he spelled out **“Pas de panique,”** meaning **“Don’t panic”** [1].

1) Introduction

A stroke does not have the same outcome for everyone. Some people regain all or nearly all of their lost abilities, while others live with lasting changes [2], such as weakness in one hand, difficulty walking, or trouble finding words. A stroke can also be fatal. The outcome depends in part on which areas of the brain are damaged, the extent of the damage, and how quickly treatment begins.

A stroke can sometimes have a single, unexpected sign. In one case report, a drooping eyelid was the only finding on neurological examination. It resolved one month after the symptoms began [3]. Severe damage to the brainstem can cause classic locked-in syndrome, which takes away speech and most voluntary movement.

Awareness is preserved, and blinking or vertical eye movements can provide a way to communicate [4]. Jean-Dominique Bauby, editor-in-chief of *Elle* magazine, had a stroke on December 8, 1995, that left him with locked-in syndrome [5]. When he awoke from a coma, he used his left eyelid to communicate [6].

Sandrine Fichou, Bauby’s speech therapist, introduced a method of communicating through letters. The person with him read out letters one at a time, and Bauby blinked when he heard the letter he wanted. That letter was recorded, and the list was read again from the beginning to select the next letter. In this way, small choices could become words and then sentences [6].

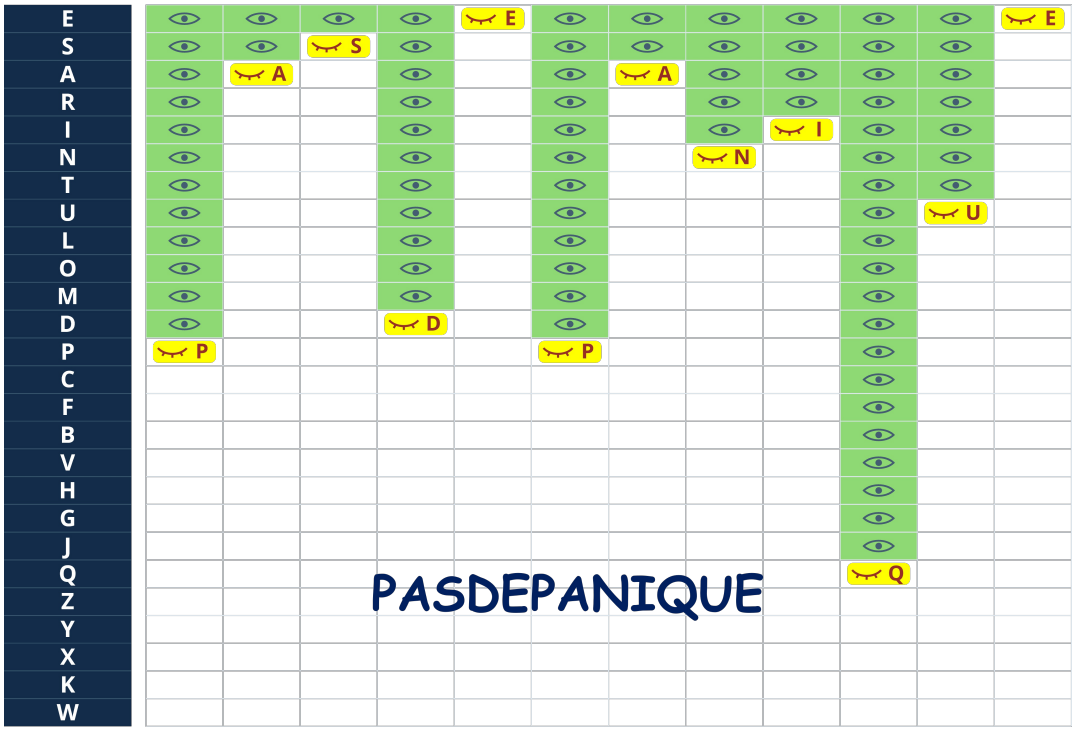
This is how he wrote *Le Scaphandre et le Papillon* (*The Diving Bell and the Butterfly*), a book about his experience of living in this condition. Bauby's work is more than an account of illness. He writes about memories, his children, hospital experiences, and journeys made possible by imagination. The book combines sadness, humour, and a desire to live. The stroke had taken away his ability to speak, but his personality as a writer came through in the text [6].

Claude Mendibil joined him to record the text. Before their sessions, Bauby composed and edited phrases in his mind, then communicated them letter by letter. Mendibil spent hours beside him, writing down the letters he selected. The process was very slow, but it allowed him to express personal and complex sentences [7].

A simple decision about how the letters were read to Bauby made the process faster. Instead of following their usual alphabetical order, the letters were read in an order based on their frequency in French, until he blinked at the letter he wanted [8].

The following problem uses Bauby's method to explore how the order of the letters affects the time needed to dictate a sentence.

Bauby died on March 9, 1997, two days after his book appeared in France [5]. The memoir he dictated one letter at a time would go on to reach readers around the world.



One blink, one letter: spelling "Pas de panique" ("Don't panic").

2) The Problem

The letters of the French alphabet appear in the following order:

A B C D E F G H I J K L M N O P Q R S T U V W X Y Z

One ordering based on letter frequency in written French is the ESARIN communication alphabet, which the ALIS guide identifies as the order used by Bauby [8]:

E S A R I N T U L O M D P C F B V H G J Q Z Y X K W

In this list, E comes first and W comes last. This is the order adopted for the present problem. Letter-frequency rankings vary with the collection of texts and the counting method; they are not identical across all French texts.

Note: The following assumptions and data are for educational purposes only. They do not necessarily reflect how Bauby and Mendibil actually communicated.

Suppose Bauby wants to communicate the opening sentence of his book to Mendibil [6]:

Derrière le rideau de toile mitée une clarté laiteuse annonce l'approche du petit matin.

The sentence means:

"Behind the moth-eaten fabric curtain, a milky light announces the approach of dawn."

Suppose that we write the sentence Bauby has formed in his mind using only capital letters without diacritical marks. For example, É and È are both treated as E. We also disregard spaces, the apostrophe, and the full stop. Under these conventions, the sentence contains 73 letters. Also assume that:

- Allow 0.5 seconds per letter for Mendibil to read it aloud and for Bauby to recognise it.
- Add 0.4 seconds for Bauby to blink at the chosen letter and for Mendibil to notice it.
- After each letter is selected, reading starts again from the beginning of the list.
- Exclude errors, corrections, breaks, ordinary blinks, and the time needed to write down each selected letter.
- Time savings from recognising a word before all its letters have been selected, predicting the next word from the preceding words, or similar effects are not considered.

Under these assumptions, calculate the dictation time in each case.

a) Mendibil uses the usual alphabetical order.

b) Mendibil uses the French frequency-based order shown above.

3) Solution

Table 1 lists each letter's positions in both orders and its count in the sentence.

Table 1) A–Z positions (blue), frequency ranks (peach), and counts (green).

$\mathcal{C}$	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
i	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
b_i	3	16	14	12	1	15	19	18	5	20	25	9	11	6	10	13	21	4	2	7	8	17	26	24	23	22
c_i	6	0	3	4	16	0	0	1	7	0	0	5	2	5	3	3	0	6	1	7	4	0	0	0	0	0

Here, $\mathcal{C}$ denotes a letter, i its alphabetical position, b_i its frequency-based position, and c_i its count in the sentence.

For alphabetical order (Figure 1), the time T_a is

$$T_a = 0.4 \times 73 + 0.5 \sum_{i=1}^{26} i c_i$$
$$= 0.4 \times 73 + 0.5(1 \times 6 + 2 \times 0 + 3 \times 3 + 4 \times 4 + 5 \times 16 + \cdots$$
$$+21 \times 4 + \cdots + 26 \times 0) = 420.2 \text{ s}$$

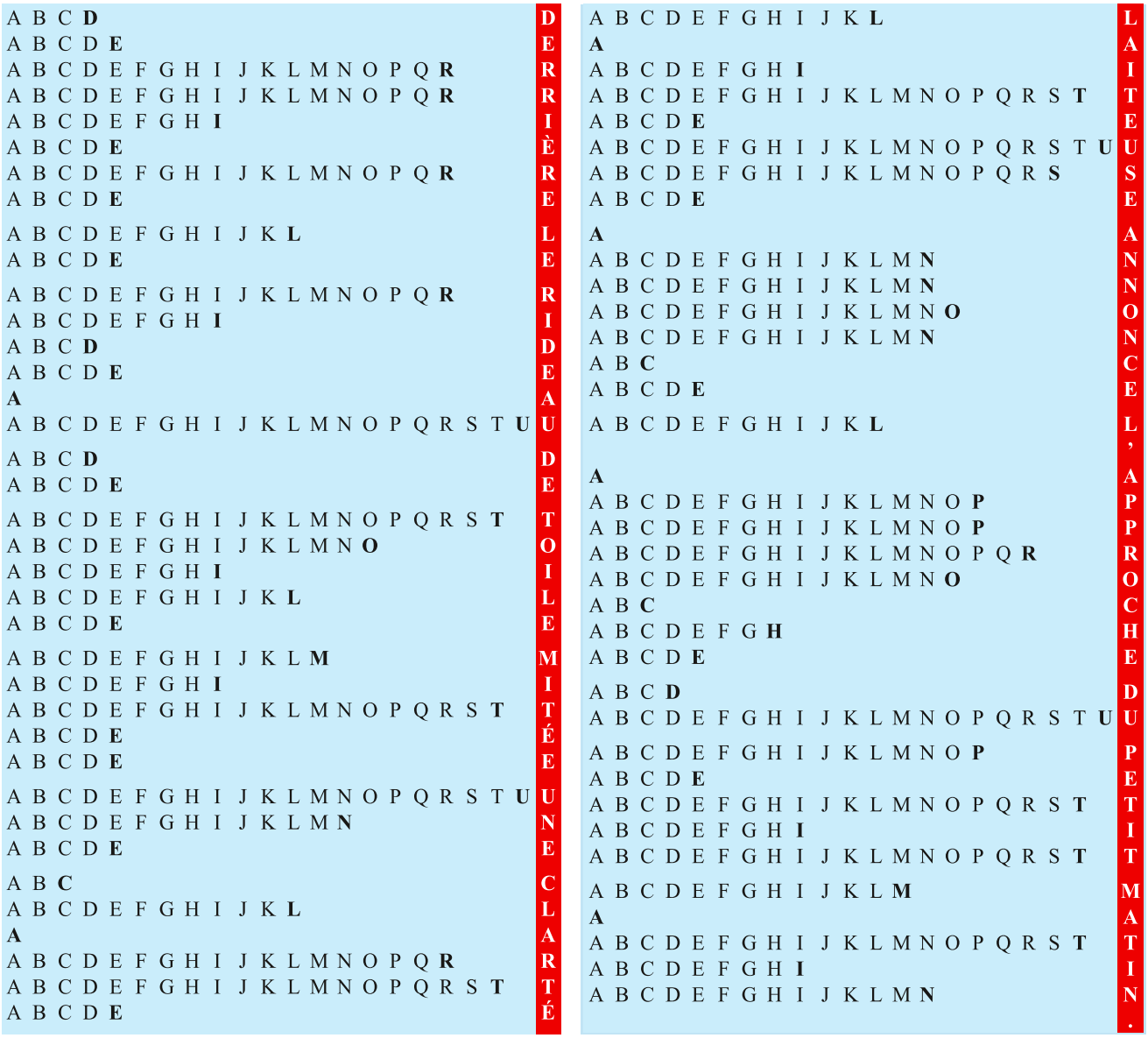


Figure 1) Selecting the letters of Bauby's opening sentence using alphabetical order (A–Z).
Red columns show the letters selected by blinking.
Read down the left panel, then the right.
Accents and punctuation are retained for readability but excluded from the timing calculations.

For frequency-based order (Figure 2), the time T_b is

$$T_b = 0.4 \times 73 + 0.5 \sum_{i=1}^{26} b_i c_i$$
$$= 0.4 \times 73 + 0.5(3 \times 6 + 16 \times 0 + 14 \times 3 + 12 \times 4 + 1 \times 16 + \cdots$$
$$+8 \times 4 + \cdots + 26 \times 0) = 254.2 \text{ s}$$

Frequency-based order saves 166 s (39.5%) under the assumptions in Section 2.

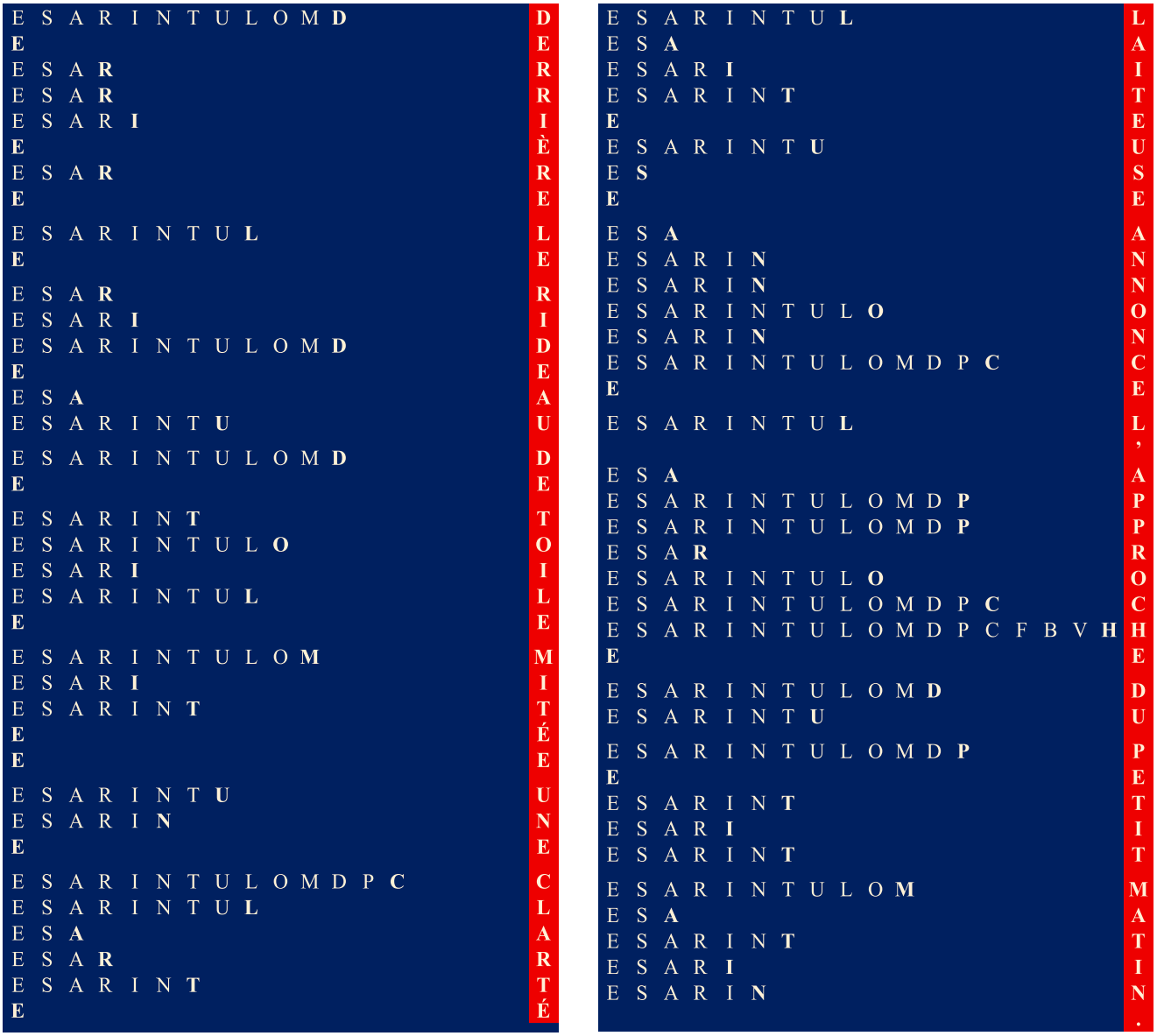


Figure 2) Selecting the letters of Bauby's opening sentence using frequency-based order (ESARIN). Red columns show the letters selected by blinking. Read down the left panel, then the right.

Accents and punctuation are retained for readability but excluded from the timing calculations.

Two related questions can also be explored:

- Choose other French sentences of about 73 letters, using the same counting rules. Calculate the percentage time saved for each sentence and compare it with 39.5%.
- What percentage of all letters in a sample of written French does each letter account for? How do these percentages compare across texts from different periods?

4) Research and Investigation

The three people below each wrote or co-wrote a book about their experiences. Read about their lives and model the communication time for a sentence from each book. Use their documented method and state your timing assumptions.

4.1) Philippe Vigand

In 1990, at the age of 32, Philippe Vigand had a stroke that left him with locked-in syndrome. He lost his ability to speak and most body movement, but eyelid movements provided a way to communicate. His wife, Stéphane, helped him select letters using an agreed communication system. Later, an adapted computer enabled him to write. They had two children at the time and later had a third [9].

Vigand began writing about his experiences in 1995. The result was *Putain de silence*, meaning "Damn Silence," published in 1997. Philippe describes learning to communicate again, and Stéphane writes about how their family adapted [9], [10].

4.2) Julia Tavalaro

After two strokes in 1966 and a prolonged coma, Julia Tavalaro lived with severe limitations in movement and speech. Her caregivers believed for years that she was in a vegetative state. She could hear and understand them. In 1973, speech therapist Arlene Kraat recognised that Tavalaro could respond with her eyes. Kraat pointed to letters on a board so Tavalaro could spell out what she wanted to say [11].

Tavalaro went on to write poetry and recount her memories. Her book *Look Up for Yes*, co-written with Richard Tayson, was published in 1997. The title recalls her first successful communication with Kraat, when she looked upward to indicate "yes" after years of isolation [11].

4.3) Kate Allatt

British runner Kate Allatt developed locked-in syndrome after a brainstem stroke. She initially communicated using blinks and a letter chart. As some movement returned, she began moving her thumb and communicating through Facebook. She recounts her experience in *Running Free* (2011) [12].

As her abilities changed, so did her communication methods; timing models should reflect the method used at each stage.

5) Connections to the Curriculum

Table 2 outlines suggested connections between the article and common curriculum topics. The level of each activity can be adjusted to students' prior knowledge.

In pairs, test both letter orders using the same sentence and reading pace. Compare measured times with predictions and explain any differences.

Table 2) Connections between the article and curriculum topics

Subject area	Suggested level	Related concepts	Activity or learning outcome
Mathematics and arithmetic	Lower and upper secondary	Addition, multiplication, decimals, percentages, and units of time	Calculate the time required by the two methods and the percentage time saving.
Statistics and data evaluation	Lower and upper secondary	Frequency tables, ranking, and the difference between a sample and a population	Compare the letter-frequency ranking for the sentence with the ranking for written French. Examine how the choice of text affects relative letter frequencies.
Algebra and modelling	Upper secondary	Variables, weighted sums, and linear functions	Use symbols to express total time as the sum of letter-reading time and blinking time; examine the effect of changing reading or blinking speed.
Probability	Upper secondary	Probability distributions and expected value	Calculate the expected number of letters read per selection for each order, using relative frequencies as estimated probabilities.
Science and biology	Lower and upper secondary	Blood circulation in the brain, the nervous system, movement control, and awareness	Explain the relationship between the location of damage and lost function, and distinguish motor impairment from lack of awareness.
Computing and algorithmic thinking	Lower and upper secondary	Sequential search, loops, counting, and optimisation	Write pseudocode or a program to clean the text, count letters, and calculate the time required for the two orders.
Design and technology	Lower and upper secondary	Accessible interfaces, feedback, and error correction	Design a letter board with clear signals for confirming and correcting selections. Compare alternatives for speed, errors, and ease of use.
Language and literature	Lower and upper secondary	Memoir writing, translation, punctuation, and language structure	Read the French sentence and analyse how personal experience is narrated.
Ethics and social studies	Lower and upper secondary	Human dignity, the right to communicate, and social participation	Discuss the consequences of mistaking inability to respond for lack of awareness, and the role of families and therapists.
Research methods	Upper secondary	Source evaluation, assumptions, limitations, and reproducibility	Explore ways to select reliable text from different references and record the sources.

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Stroke: An Experience Between Science and Life

> You never really understand a person until you consider things from his point of view… until you climb into his skin and walk around in it.
>
> **Harper Lee, *To Kill a Mockingbird* [1, ch. 3].**

When a patient describes the sharp pain of biting down on a sore tooth, a dentist may know the feeling firsthand. An eye specialist may remember how frustrating it is to read when the letters blur. In many areas of medicine, everyday experiences like these help clinicians get a sense of what their patients are going through.

A stroke can be harder to imagine. A neurologist may recognize sudden difficulty speaking or weakness in one arm as a warning sign [2]–[4]. For the person experiencing it, the first clue may come during an ordinary task, like reaching for a cup and finding that it takes more effort than expected. What is it like to recognize a warning sign in your own body?

Neuroanatomist Jill Bolte Taylor had spent years studying the brain when she experienced a stroke herself. In her memoir, *My Stroke of Insight*, she describes changes in how she perceived her surroundings and in her sense of self. As the stroke progressed, it became harder for her to understand what was happening [5].

In her TED talk, Taylor describes struggling to telephone a colleague for help. Unable to read the number normally, she matched the shapes on a business card to those on the telephone keypad. She also struggled to remember which digits she had already entered. When the call connected, she could neither understand her colleague's words nor produce the words she intended to say. She had recognized the need for help, yet carrying out the steps to obtain it was itself a struggle. Her account turns an ordinary telephone call into a vivid example of how unfamiliar an everyday task had become [6].

Taylor's account inspired the fictional story that follows. When neurologist Noah Hale has a stroke, a dialogue takes shape in his mind. As **Dr. Hale**, he draws on his clinical training to interpret the signs. As **Noah**, the patient, he tries to put what he is experiencing into words.

October 29, 2019, was, for many, a day like any other. Except that it was World Stroke Day, and, as on the days before and after it, thousands of people around the world experienced a stroke, many of whom either lost their lives or were left with lasting disability. But for one among those thousands, Dr. Noah Hale, a neurologist, that day was different. Time and again, through his profession, he had listened to the details of stroke from his patients; yet… until that day… he had never experienced it himself.

It was around seven in the morning. Noah opened his eyes. Something… was not quite right. The room was the same, yet an invisible distance seemed to separate him from the objects within it. He looked at the clock; the numbers were visible, but reading them took longer than it should have.

He got out of bed. His legs moved, though not with their usual certainty. He walked toward the desk to pick up the phone. His right hand lifted… but slower than expected.

He tried to say a simple sentence. But the words would not come together.

Noah: Something… isn't right…
Dr. Hale: Stay calm… let's look at this step by step.
Noah: My hand… it feels like it's lagging behind me…
Dr. Hale: Weakness on one side…
Noah: I want to speak… but…
Dr. Hale: Difficulty forming words…
Dr. Hale (more quietly)**:** This pattern… feels familiar.
Noah: What is happening to me?
Dr. Hale: Your brain may be experiencing an acute event… something we clinically recognize as a stroke. We need emergency help… now.
Noah: I feel like I'm losing something… but I'm still… here…
Dr. Hale: Yes… and that awareness… is still with you.



October 29 – World Stroke Day, designated in 2006 by the World Stroke Organization (WSO) to raise awareness and improve stroke prevention and care [7, p. 16].

Dr. Hale: For years, I had only heard this moment described by my patients… fragmented… incomplete… never fully graspable.
But now… for the first time… I am witnessing it from within. This is not something that can be learned from books.
Noah: So… does it matter?
Dr. Hale (softly, with depth)**:** This understanding… is profoundly valuable. Not because the stroke itself holds value, but because what you are perceiving within it is something very few physicians ever have access to. You are seeing the brain… from inside its own disruption. That is not a small thing.
Noah: If I return…
Dr. Hale: When you return, you will no longer be someone who merely knows stroke. You will be someone who has lived it. And that difference…can change the lives of others.
Dr. Hale (very gently)**:** That is why… I thank you.
Noah: Thank… myself?
Dr. Hale: For not turning away from this moment… for seeing it, even in its disarray, and allowing it to be known. This is what can build a bridge between science and life.

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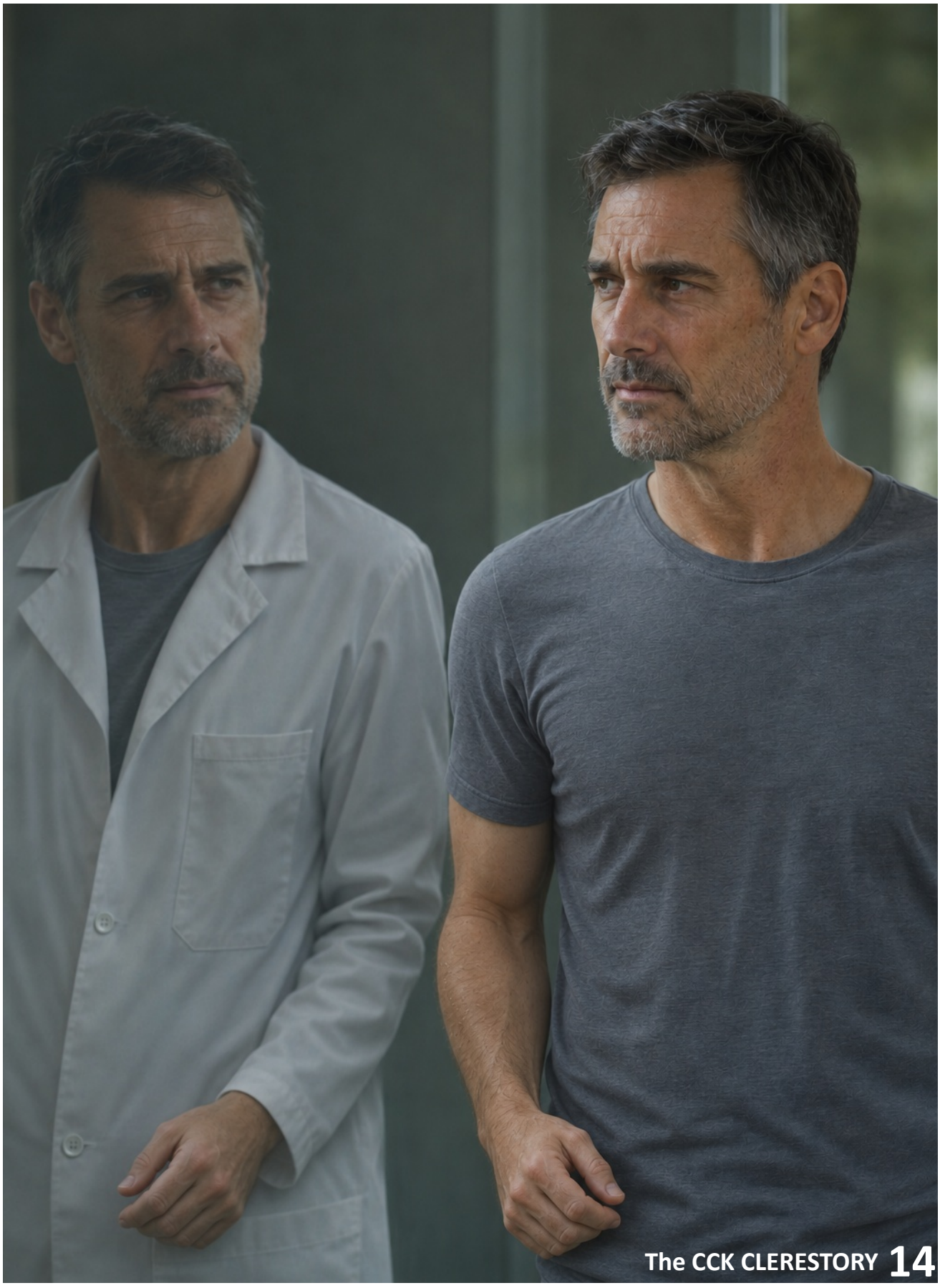


From Emergency Call to Hospital Arrival

1) Background

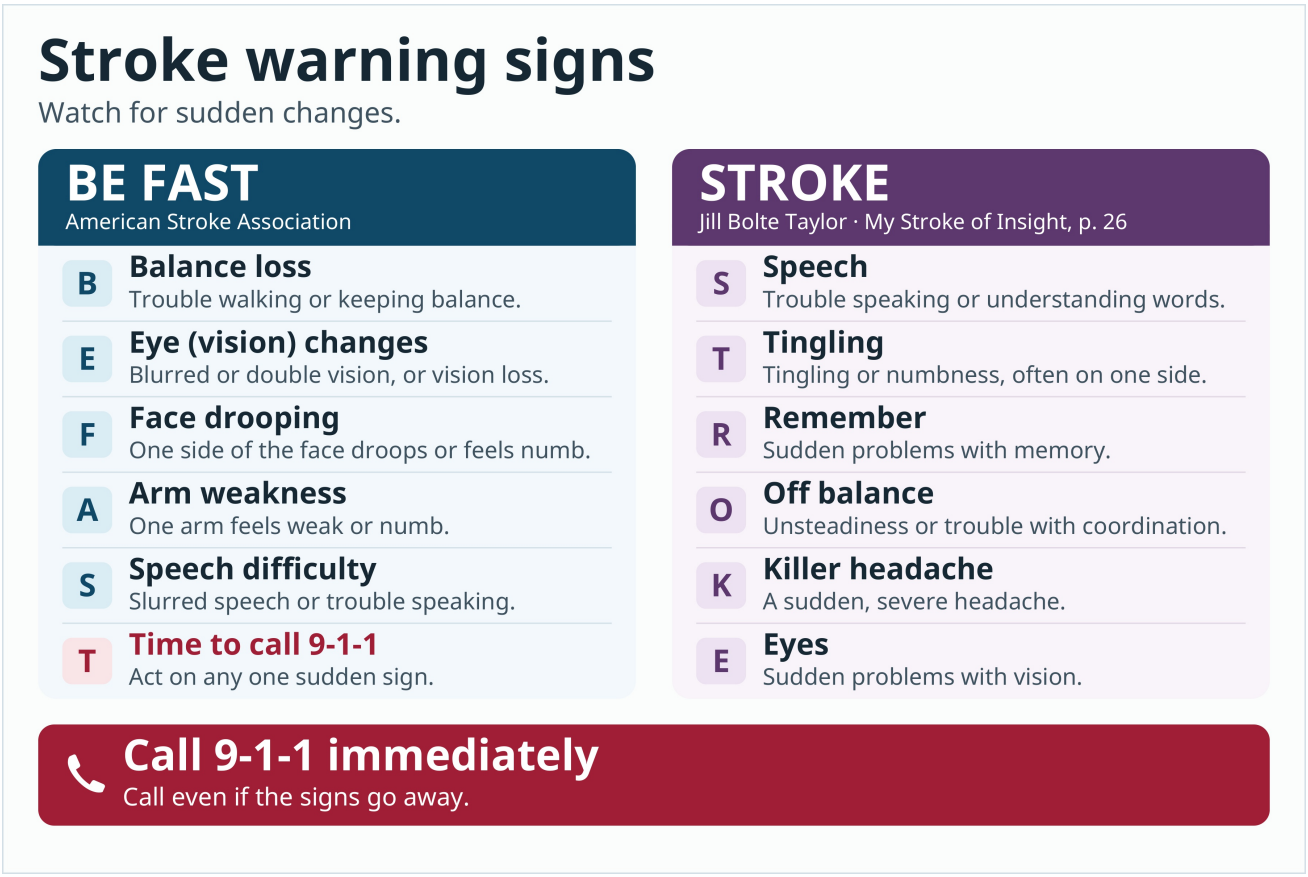
In stroke care, delays in starting treatment can allow brain injury to progress and reduce the chance of recovery. In practice, even reducing transport time to the hospital by tens of seconds can give the stroke team an earlier opportunity to assess the patient and begin appropriate treatment. For this reason, emergency medical teams plan and train to reduce avoidable delays in getting stroke patients to hospital.

2) Problem statement

At 14:05, an emergency call reports that a person has suddenly developed severe weakness in the right side of the face and arm, along with speech disturbance.

The ambulance team departs from the base for the patient's home at 14:06:00. The motion of the ambulance is described as follows: starting from rest, it accelerates with constant acceleration a_1 until it reaches the constant speed v. Near the patient's home, it decelerates with constant acceleration a_2 until it comes to rest next to the house (the same pattern holds for the trip from the home to the hospital). The on-scene time required to load the patient is t_{scene}, after which the ambulance departs for the hospital. D_1 is the distance from the base to the home, and D_2 is the distance from the home to the hospital.





Consider the following data for this problem:

$$a_1 = 1.5\ \mathrm{m/s^2}, a_2 = -2.0\ \mathrm{m/s^2}, v = 80\ \mathrm{km/h}, \mathrm{t_{scene}} = 4\ \mathrm{min}, D_1 = 3.6\ \mathrm{km}, D_2 = 8\ \mathrm{km}$$

a) At what clock time does the ambulance arrive at the hospital?

b) On its way from the patient's home, the ambulance is $D_3 = 3.3$ km from the hospital when a car ahead travelling at $u = 20$ km/h fails to yield despite the warnings. The ambulance reduces its speed with constant acceleration a_2 until its speed reaches u. When the ambulance is $D_4 = 3$ km from the hospital, the car finally pulls over completely and clears the way. At this point, the ambulance accelerates with constant acceleration a_1 until it reaches the constant speed v, and near the hospital it again decelerates with constant acceleration a_2 and comes to rest next to the hospital. In this case, at what clock time does the ambulance arrive at the hospital?

c) Sketch the speed–time and distance–time graphs for the entire motion of the ambulance in both cases (a) and (b).

d) In a short paragraph (2–3 sentences), explain why reducing the time to hospital for a patient with stroke (even by as little as 30 seconds) is clinically very important (Qualitative explanation).

3) Solutions

The given speeds in m/s and distances in m are:

$$v = 80/3.6 \approx 22.2 \text{ m/s}, u = 20/3.6 \approx 5.6 \text{ m/s}, D_1 = 3600 \text{ m},$$
$$D_2 = 8000 \text{ m}, D_3 = 3300 \text{ m}, D_4 = 3000 \text{ m}.$$

a) Let t_1 be the time it takes for the ambulance to accelerate from rest (when leaving the base) with acceleration a_1 to the speed v. Then:

$$t_1 = v/a_1 = 22.2/1.5 = 14.8\text{s}$$

The distance covered in this time is:

$$d_1 = 0.5a_1t_1^2 = 0.5 \times 1.5 \times 14.8^2 \approx 164\text{m}$$

Let t_2 be the time it takes to decelerate from speed v to rest (when reaching the home) with acceleration a_2. Then:

$$t_2 = (0 - v)/a_2 = (0 - 22.2)/-2 = 11.1\text{s}$$

The distance covered in this time is:

$$d_2 = vt_2 + 0.5a_2t_2^2 = 22.2 \times 11.1 - 0.5 \times 2 \times 11.1^2 = 123.21 \text{ m}$$

The distance $d_3 = D_1 - d_1 - d_2$ is traveled at the constant speed v in the middle part of the motion from the base to the home:

$$d_3 = D_1 - d_1 - d_2 = 3600 - 164 - 123.21 = 3312.79 \text{ m}$$

The corresponding time t_3 for this distance is:

$$t_3 = d_3/v = 3312.79/22.2 \approx 149.22 \text{ s}$$



Therefore, the total time T_1 it takes the ambulance to reach the patient's home is:

$$T_1 = t_1 + t_2 + t_3 = 14.8 + 11.1 + 149.22 = 175.12 \text{ s}$$

The same times t_1 and t_2, and the corresponding distances d_1 and d_2, also apply to the start and end of the trip from the patient's home to the hospital. Thus, the distance $d_4 = D_2 - d_1 - d_2$ which is traveled at constant speed v in the middle part of the motion from the home to the hospital, is:

$$d_4 = D_2 - d_1 - d_2 = 8000 - 164 - 123.21 = 7712.79 \text{ m}$$

The corresponding time t_4 for this distance is:

$$t_4 = d_4/v = 7712.79/22.2 \approx 347.42 \text{ s}$$

Hence, the total time T_2 it takes the ambulance to go from the patient's home to the hospital is:

$$T_2 = t_1 + t_2 + t_4 = 14.8 + 11.1 + 347.42 = 373.32 \text{ s}$$

Taking into account the time from receiving the call at the base (14:05), the one-minute delay before departure (the ambulance leaves at 14:06), the travel time T_1 to reach the home, the on-scene time to load the patient ($t_{\text{scene}} = 4 \text{ min} = 240 \text{ s}$), and the travel time T_2 from the home to the hospital, the total elapsed time is:

$$T = 60 + \text{t}_{\text{scence}} + T_1 + T_2 = 60 + 240 + 175.12 + 373.32 = 848.44 \text{ s} \approx 14 \text{ min and } 8 \text{ s}$$

Therefore, the ambulance arrives at the hospital at approximately 14:19:08.



A British Columbia ambulance displaying the FAST stroke-awareness message. Photo: Mitchell Smith / Wikimedia Commons, CC BY 2.0.

b) Let t_5 be the time it takes for the ambulance to slow down from speed v (when it is at distance D_3 from the hospital) with acceleration a_2 until its speed reaches u. Then:

$$t_5 = \frac{u - v}{a_2} = \frac{5.6 - 22.2}{-2} = 8.3 \text{ s}$$

The distance covered in this time is:

$$d_5 = vt_5 + 0.5a_2t_5^2 = 22.2 \times 8.3 - 0.5 \times 2 \times 8.3^2 \approx 115\text{m}$$

Therefore, the distance $d_6 = D_3 - D_4 - d_5 = 185$ m is traveled at the constant speed u. The corresponding time t_6 for this distance is

$$t_6 = \frac{d_6}{u} = \frac{185}{5.6} \approx 33\text{s}$$

Let t_7 be the time it takes to accelerate again from speed u to speed v with acceleration a_1. Then:

$$t_7 = \frac{v - u}{a_1} = \frac{22.2 - 5.6}{1.5} \approx 11.1s$$

The distance covered in this time is:

$$d_7 = ut_7 + 0.5a_1t_7^2 = 5.6 \times 11.1 + 0.5 \times 1.5 \times 11.1^2 \approx 155 \text{ m}$$

Hence, the total distance over which the ambulance is forced to slow down and then speed up again because of the obstacle is:

$$D = D_3 - D_4 + d_7 = 300 + 155 = 455 \text{ m}$$

The time spent over this distance is:

$$T_\text{V} = t_5 + t_6 + t_7 = 8.3 + 33 + 11.1 = 52.4 \text{ s}$$

If there were no obstacle, the time T_r needed for the ambulance to travel the same distance $D = 455$ m at speed v would be:

$$T_\text{r} = \frac{D}{v} = \frac{455}{22.2} \approx 20.5 \text{ s}$$

Thus the obstacle adds a delay of $T_\text{V} - T_\text{r} = 52.4 - 20.5 = 31.9$ s in reaching the hospital.

The car delays the ambulance by approximately 31.9 s. The ambulance therefore arrives at the hospital at approximately 14:19:40.

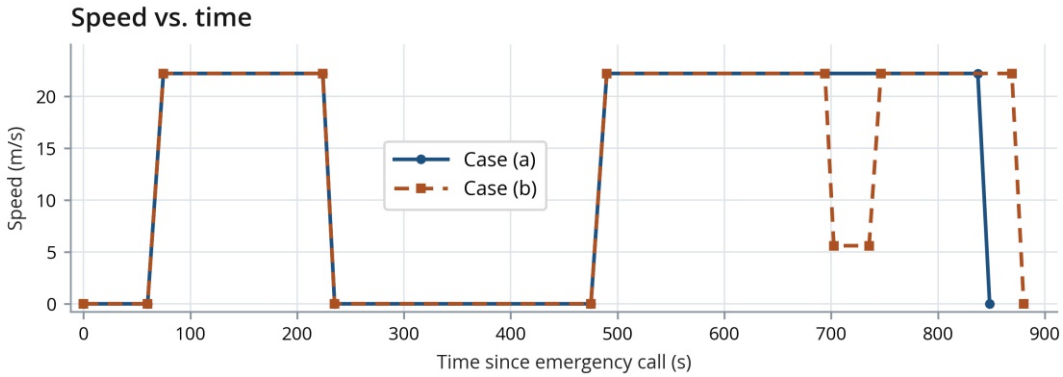
A study of ambulance footage from Germany found that in about 100 out of 1,177 traffic situations where an ambulance needed the right of way, one or more road users did not notice it approaching and did not give way.

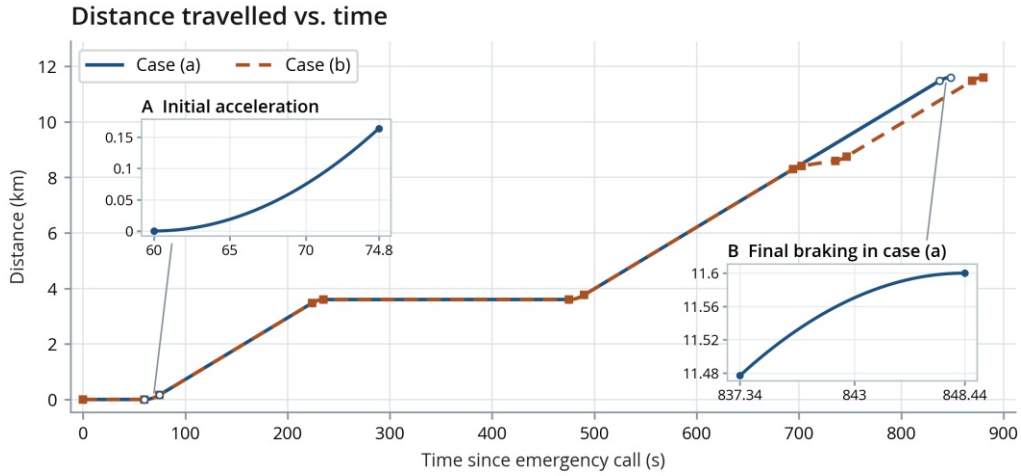
Prohn & Herbig (2023), doi:10.5811/westjem.2022.8.56114

c)

Table 1) Ambulance speed at key times after the emergency call

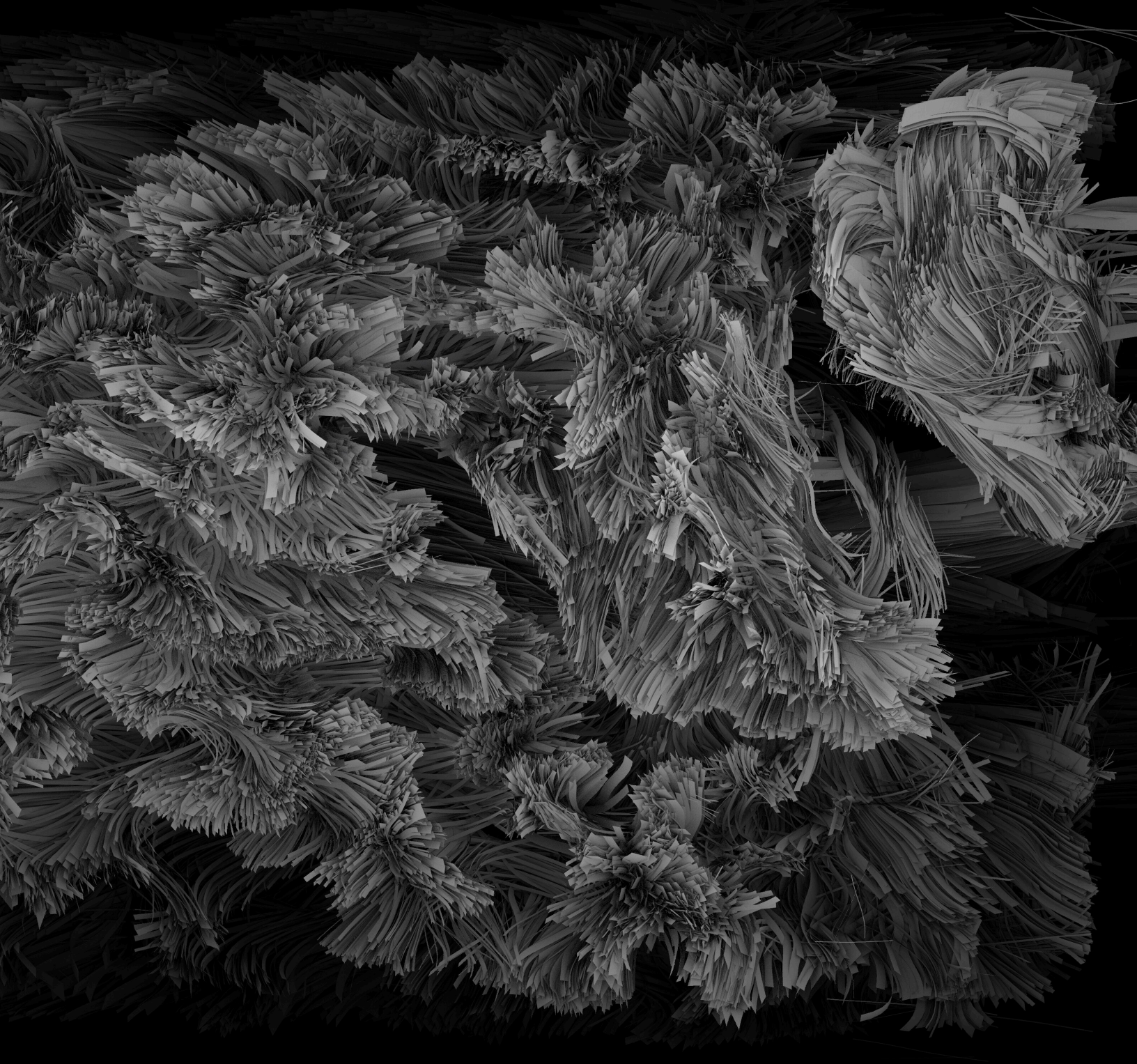
Case (a)		Case (b)	
Time (s)	**Speed (m/s)**	**Time (s)**	**Speed (m/s)**
0.00	0.0	0.00	0.0
60.00	0.0	60.00	0.0
74.80	22.2	74.80	22.2
224.02	22.2	224.02	22.2
235.12	0.0	235.12	0.0
475.12	0.0	475.12	0.0
489.92	22.2	489.92	22.2
837.34	22.2	694.24	22.2
848.44	0.0	702.54	5.6
		735.54	5.6
		746.64	22.2
		869.24	22.2
		880.34	0.0

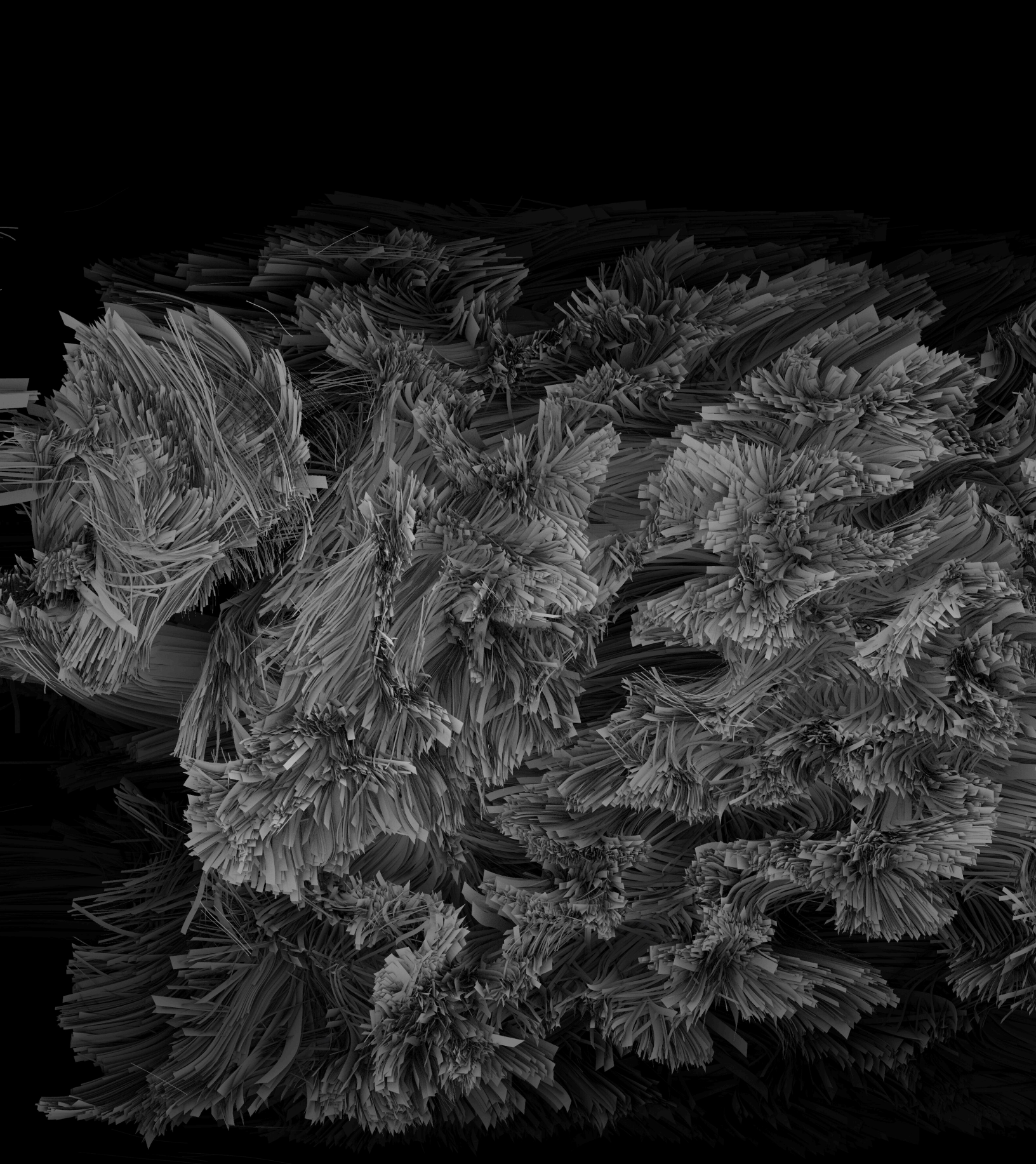




d) Arriving at the hospital sooner gives the stroke team more time to assess the patient, identify the type of stroke, and begin the appropriate treatment. Those seconds can be especially valuable when a blocked artery can be reopened, because restoring blood flow sooner can improve the chances of recovery.

Unfolded brain connections: White-matter pathways estimated from diffusion-weighted MRI are displayed using a Mercator transformation. In cartography, this method maps a spherical surface onto a flat map, preserving local angles while distorting areas. Here, it reshapes the reconstructed network to bring multiple views of the brain's complex connections into a single image.
Katja Heuer and Roberto Toro / Wellcome Collection / CC BY 4.0 (cropped).





Grip Strength Recovery After Stroke

1) Background

A stroke can affect motor control, speech, and cognition. During rehabilitation, repeated practice of tasks such as reaching and grasping can help the brain adapt and improve control of the affected hand [1], [2].

2) Problem Statement

Reza is a 70-year-old man recovering from a stroke that has weakened the right side of his body. As part of his rehabilitation program, Reza's right-hand grip strength is measured once a week for eight weeks to track his progress. The same hand dynamometer and testing position are used each time. He has promised his grandson that, with regular practice, he will soon rebuild his physical strength. The recorded grip strengths (in kg) are given in table 1.

Table 1) Grip Strength (kg*) over 8 Weeks

Week	1	2	3	4	5	6	7	8
grip strength	12	14	16	17	19	21	22	24

* The dynamometer displays grip force as "kg," which here means kilogram-force (kgf). One kilogram-force is approximately 9.81 newtons (N).

a) Plot a graph of grip strength vs. time (weeks).

b) Calculate the average weekly improvement rate.

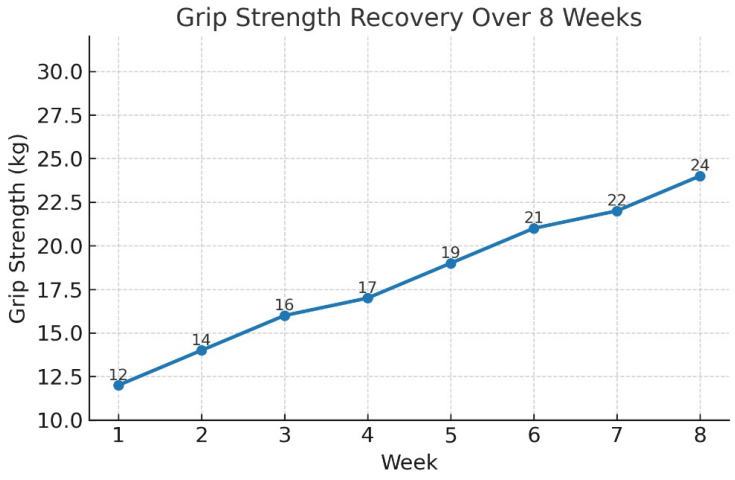
c) If the patient's pre-stroke grip strength was 30 kg, estimate how many more weeks are required to return to baseline at the same improvement rate.

d) Explain why Reza's grip strength might improve more slowly after Week 8.

e) Does daily practice shorten simple visual reaction time? Design an experiment.

3) Solutions

a)





b) Average weekly improvement rate:

Step 1) Total improvement $= 24 - 12 = 12$ kgf

Step 2) Number of intervals: From Week 1 to Week 8 there are 7 Weekly intervals. The Week 1 reading marks the starting point. Each weekly interval runs from one measurement to the next, so eight readings span seven intervals.

Step 3) Average weekly improvement $= \frac{12 \text{ kgf}}{7 \text{ weeks}} \approx 1.71$ kgf/week

Meaning: Between Weeks 1 and 8, Reza's grip strength increased by an average of about 1.7 kgf per week.

c) At the same average rate, Reza's grip strength would reach 30 kg about 3.5 weeks after Week 8. Adding this time to Week 8 gives Week 11.5, which lies between the scheduled tests at Weeks 11 and 12. With weekly testing, the model first predicts a reading of 30 kg or more at Week 12. This estimate assumes that the rate stays constant.

d) Early gains in grip strength can come partly from the brain's natural recovery after a stroke. As this early phase passes, further gains may take longer. Fatigue after a stroke can also make it harder to practise regularly.

e) Short experiment to test reaction time improvement:

Design an experiment with two groups of volunteers. Randomly assign volunteers to the two groups. Use the same device, test conditions, and number of trials for every participant at both assessments:

- **Group A (Training Group):**
  This group performs short reaction time exercises every day for 2 weeks. For example, they use a reaction timer where an LED light turns on at random times and they must press a button as quickly as possible.
- **Group B (Control Group):**
  This group does not do any specific reaction time training during the same 2-week period. They continue their normal daily activities.

Procedure:

1. Before the training starts, measure the average reaction time of each person in both groups using the LED light + button device. Record these values as the "before" measurements.
2. Group A then practices reaction time exercises daily, while Group B does not.
3. After 2 weeks, measure the reaction time of all participants again and record these values as the "after" measurements.
4. Calculate the percentage improvement in reaction time for each person:

$$\text{Percentage improvement} = \frac{\text{Before} - \text{After}}{\text{Before}} \times 100$$

5. First, calculate each group's average from the percentage improvements of its individual participants. Plot the results on a graph (for example, bar graph) comparing the average percentage improvement of Group A and Group B to see whether daily reaction time training leads to greater improvement.



4) Curriculum Connection

Table 2 shows how the grip strength problem connects to the B.C. curriculum.

Table 2. Curriculum connections for the grip strength problem

Grade(s)	Subject / Topic	Connection to the Problem
6	Science 6 – Human Body Systems	How the nervous system helps control hand movement
8–9	Mathematics 8–9 – Linear Relations	Plotting weekly measurements and using a linear model to make a prediction
8–10	Physical and Health Education	How physical activity supports strength and health
10	Foundations of Mathematics and Pre-calculus 10	Calculating the average rate of change and estimating when grip strength could reach 30 kg
10	Science 10 – Planning Investigations	Designing a controlled experiment to test the effect of daily practice on visual reaction time
11	Physics 11 – Forces	Using a dynamometer to measure the force exerted by the hand
12	Anatomy and Physiology 12 – Nervous System	Connecting nervous system function to changes in hand movement after stroke

References

[1] S. A. Billinger et al., "Physical activity and exercise recommendations for stroke survivors: A statement for healthcare professionals from the American Heart Association/American Stroke Association," *Stroke*, vol. 45, no. 8, pp. 2532–2553, Aug. 2014, doi: 10.1161/STR.0000000000000022.

[2] R. J. Nudo, "Recovery after brain injury: Mechanisms and principles," *Front. Hum. Neurosci.*, vol. 7, Dec. 2013, Art. no. 887, doi: 10.3389/fnhum.2013.00887.

Further Reading

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[4] Y. Okubo, D. Schoene, and S. R. Lord, "Step training improves reaction time, gait and balance and reduces falls in older people: A systematic review and meta-analysis," *Br. J. Sports Med.*, vol. 51, no. 7, pp. 586–593, Apr. 2017, doi: 10.1136/bjsports-2015-095452.

After Nine Years, She Opened Her Hand Again

An experimental spinal cord stimulation system delivers electrical pulses through two thin electrodes placed near the spinal cord in the neck. The pulses help spinal circuits respond to signals from the brain when a person tries to move their arm or hand. Separate surface sensors attached to the arm and hand recorded muscle activity during testing. The initial report described two participants whose electrodes were removed after 29 days [1].

Heather Rendulic had five strokes in 11 months [2]. On her first day of testing, with the stimulation on, she fully opened her left hand for the first time in nine years. She later used that hand to lift a can of soup. When the researchers tested her with a handheld dynamometer, her grip strength was 40% higher with the stimulation on than with it off [1].

"It felt like my brain could connect to my left arm and hand again," Rendulic told *STAT* [3].

[1] M. P. Powell *et al.*, "Epidural stimulation of the cervical spinal cord for post-stroke upper-limb paresis," *Nat. Med.*, vol. 29, no. 3, pp. 689–699, Mar. 2023, doi: 10.1038/s41591-022-02202-6.

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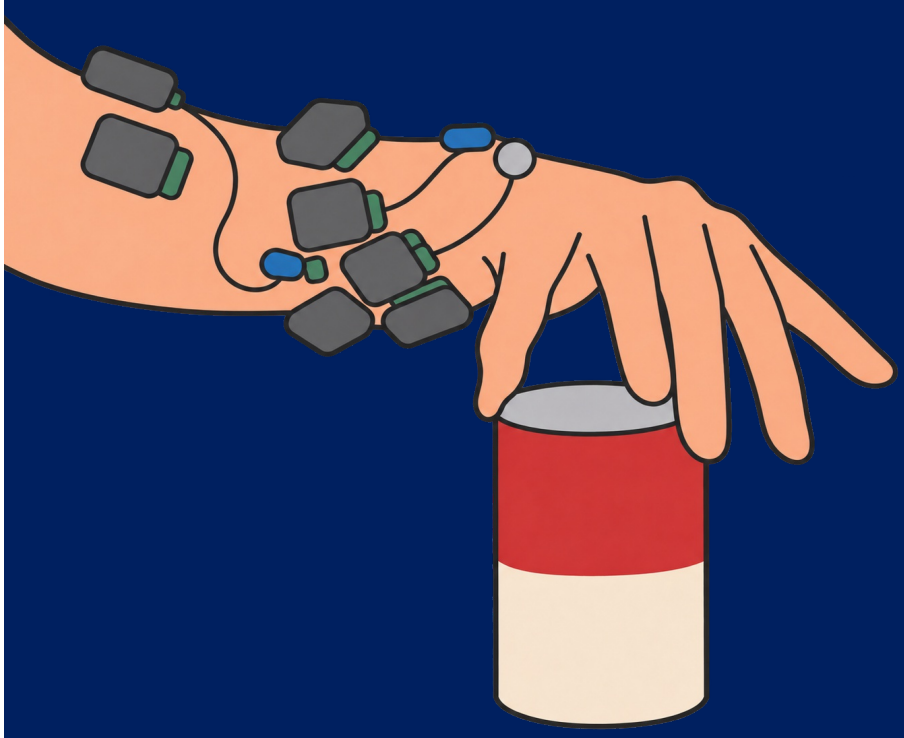
[3] L. Lawrence, "A device restored hand movement for two stroke survivors. Researchers want to take it mainstream," *STAT*, Feb. 20, 2023. [Online]. Available: https://www.statnews.com/2023/02/20/stroke-paralysis-spinal-cord-stimulation/



Oxygen Supply, Stroke, and Neuronal Survival

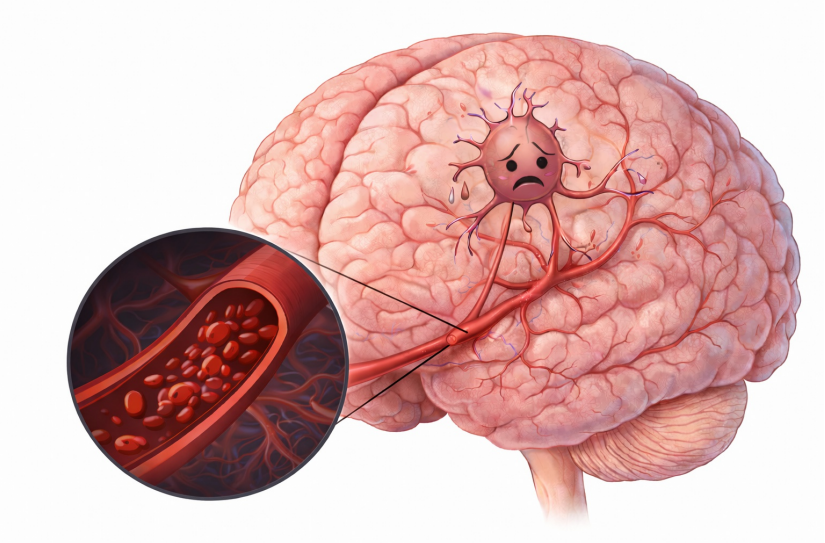
1) Background

The brain is one of the body's most energy-demanding organs. Although it makes up only about 2% of body weight, it consumes nearly 20% of the body's oxygen and energy [1]. To stay alive, the brain (like an engine) requires a constant supply of fuel (glucose) and oxygen. Neurons (nerve cells) rely on aerobic respiration, meaning they need oxygen to fully metabolize glucose and generate a large amount of adenosine triphosphate (ATP), the cell's energy currency.

Whenever a neuron needs energy (e.g. for movement, thinking, pumping molecules, or growth), ATP molecules act like small batteries, releasing their stored energy.

When an artery supplying the brain is blocked, less oxygen and glucose reach the affected tissue. ATP production falls, and anaerobic glycolysis can supply only a limited amount of ATP. Prolonged ischemia can lead to neuronal death.

Note: The following numbers and models are simplified approximations for educational purposes and do not reflect exact clinical data. They are intended to help students engage with the concepts and solve related problems.



Reduced blood flow limits the supply of oxygen and glucose to brain tissue. ATP production falls, and lactate can accumulate. If blood flow stays too low, neurons can die.

2) Problem Statement

Oxygen in the blood is carried mainly by hemoglobin (the protein in red blood cells). Each gram of hemoglobin can carry about 1.34 mL of oxygen [2]. In a healthy adult, the hemoglobin concentration is about 15 g per 100 mL of blood. Use 98% arterial oxygen saturation and consider only oxygen bound to hemoglobin.

Tasks:

a) Calculate how many milliliters of oxygen are carried in every 100 mL of arterial blood.

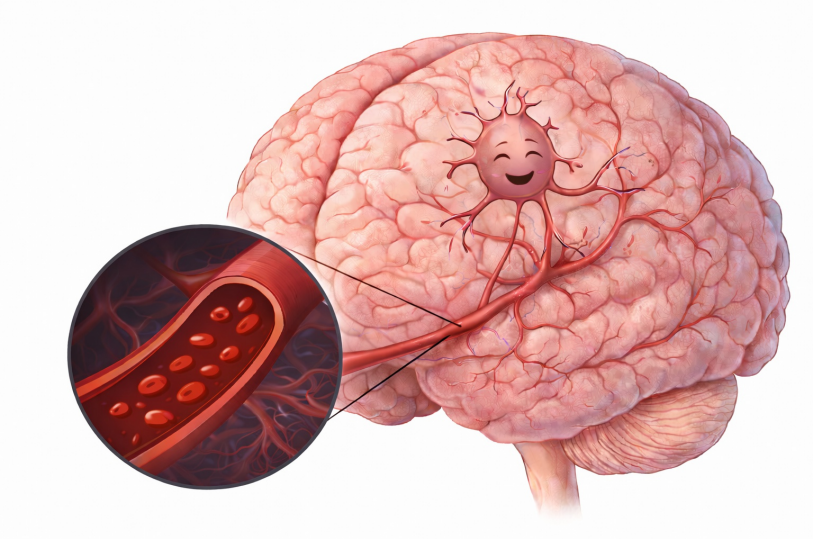
b) An 80 cm^3 region of the brain normally receives about 40 mL of blood per minute. Suppose blood flow to this region is cut off for 5 minutes. Calculate how much oxygen fails to reach this brain region in that time.

c) Suppose there are initially 2 billion neurons in the region from part (b). For this simplified model, assume that 10% of the surviving neurons die each minute while blood flow is interrupted. How many neurons are still alive after 5 minutes?

d) In the same survival model, suppose blood flow is restored 40 minutes after stroke onset in one case (hypothetical Drug A) and 60 minutes after onset in another (hypothetical Drug B).

d-1) How many additional neurons are alive when blood flow is restored at 40 minutes? Express this number as a percentage of the initial neuron count.

d-2) Explain why restoring blood flow sooner can improve recovery after an ischemic stroke.



Early restoration of blood flow brings oxygen and glucose back to the affected tissue. This can help viable neurons resume aerobic ATP production and improve the chances of recovery.

3) Solutions

a) At 98% arterial oxygen saturation, the amount of oxygen bound to hemoglobin in 100 mL of arterial blood is:

$$(15.0\ \text{g Hb}\ /100\ \text{mL}) \times\ (1.34\ \text{mL}\ O_2/\text{g Hb}\ ) \times\ 98\%\ \approx\ 19.7\ \text{mL}\ O_2/100\ \text{mL}.$$

b) Oxygen not delivered in 5 minutes (normal flow = 40 mL/min):

$$(0.197\ \text{mL}\ O_2/\text{mL blood}\ ) \times\ (40\ \text{mL blood/min})\ \times\ 5\ \text{min}\ \approx\ 39.4\ \text{mL}\ O_2$$

c) Neuron survival after 5 minutes (90% survive each minute):

$$2{,}000{,}000{,}000\ \times\ (1-0.1)^5\ \approx\ 1.18\ \text{billion}$$

d) Drug A versus Drug B

d-1) Difference in surviving neurons (40 min with Drug A vs. 60 min with Drug B):

$$2{,}000{,}000{,}000\ \times\ ((1-0.1)^{40}-(1-0.1)^{60})\ \approx\ 25{,}967{,}745$$

Percentage of the initial 2 billion neurons: $100\%\ \times\ \frac{25{,}967{,}745}{2{,}000{,}000{,}000} \approx 1.3\%$

d-2) Interpretation:

In this model, blood flow returns 20 minutes sooner with Drug A, leaving about 26 million more neurons alive. Restoring blood flow sooner after an ischemic stroke can bring oxygen and glucose back to brain tissue that is still viable, limiting damage and improving the chance of recovery.

Table 1) Curriculum Connections

Grade/Level	Subject	Relevant Topics	Connection to the Problem
12	Anatomy & Physiology	Blood, hemoglobin, and oxygen transport	Relates hemoglobin-bound oxygen in arterial blood to oxygen delivery to the brain.
12	Anatomy & Physiology	Aerobic respiration, anaerobic glycolysis, and ATP	Reduced oxygen delivery limits aerobic ATP production during ischemia.
12	Anatomy & Physiology	Nervous system and homeostasis	Connects interrupted blood flow and reduced oxygen delivery to neuron survival.
12	Pre-calculus, Foundations	Exponential decay, percentages, and scientific notation	Survival model $N(t) = N_0(1-a)^t$, with a the fraction of survivors lost per minute and t in minutes.
11-12	Chemistry (supporting)	Concentration, ratios, and unit conversions	Uses hemoglobin concentration and binding capacity to calculate oxygen content per 100 mL of blood.
University (intro level)	Health Science, Anatomy, Physiology	Ischemic stroke and timing of blood flow restoration	Compares modeled neuron survival when blood flow returns at 40 min (Drug A) and 60 min (Drug B).

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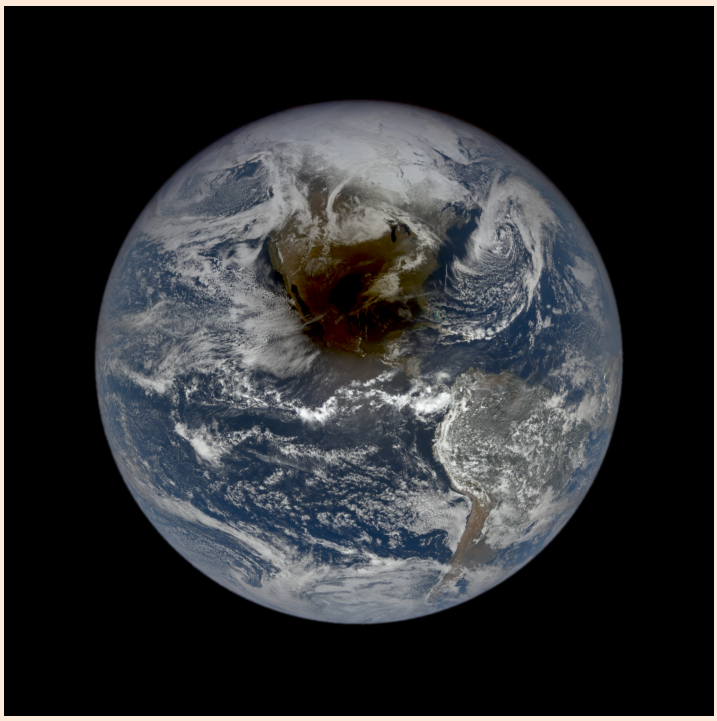
[2] R. M. Leach and D. F. Treacher, "The pulmonary physician in critical care • 2: Oxygen delivery and consumption in the critically ill," *Thorax*, vol. 57, no. 2, pp. 170–177, Feb. 2002, doi: 10.1136/thorax.57.2.170.

When Brain Cells Fall Silent

In 1981, Astrup and colleagues described the *ischemic penumbra* as a region of living brain tissue where reduced blood flow suppresses normal electrical activity. If blood flow returns soon enough, some of this tissue can recover [1]. The word *penumbra* also refers to the partial shadow cast during an eclipse.

[1] J. Astrup, B. K. Siesjö, and L. Symon, "Thresholds in cerebral ischemia—the ischemic penumbra," *Stroke*, vol. 12, no. 6, pp. 723–725, Nov./Dec. 1981, doi: 10.1161/01.STR.12.6.723.



The Moon's shadow over North America during the April 8, 2024 solar eclipse. The lighter outer part of the shadow is the *penumbra*.
Image courtesy of the NASA EPIC Team.

Decompressive Craniectomy & Intracranial Pressure

1) Background

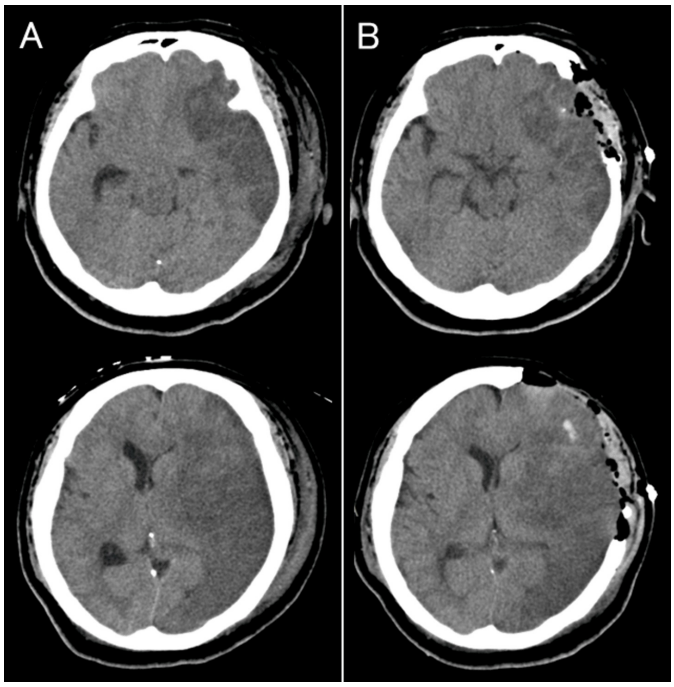
The brain is enclosed within the rigid skull. After a large ischemic stroke, swelling (cerebral edema) can raise intracranial pressure (ICP). This can lower cerebral perfusion pressure (CPP) and limit blood flow. Removing part of the skull (decompressive craniectomy) gives the swollen brain room to expand and can lower ICP. In selected patients, surgery can improve survival [1], [2].

Cerebral perfusion pressure is calculated as CPP = MAP − ICP,

where MAP is the mean arterial pressure, held at 95 mmHg in the exercise.

Let the baseline pressure before swelling be ICP_0. In this exercise, ICP before surgery is estimated using the model $ICP \approx ICP_0 + k\Delta V$.

Here, ΔV is the swelling volume, and k is the rise in ICP per unit of swelling volume in the model. The values of ΔV and k are hypothetical. The actual intracranial pressure–volume relationship is nonlinear and changes after decompressive craniectomy.



A: CT on day 1, before surgery, shows swelling and midline shift after a large left-sided ischemic stroke.

B: CT on day 2, after decompressive craniectomy, shows reduced midline shift (sideways displacement of central brain structures). Each panel shows two axial (horizontal) CT slices at different levels of the brain.

Source: Hatakenaka et al., *Cureus*, 2026 (Fig. 6, panels A–B only).

DOI 10.7759/cureus.106001. CC BY 4.0.

2) Problem Statement

A hypothetical patient develops brain swelling after a large ischemic stroke.

ICP_0 = 10 mmHg, MAP = 95 mmHg, ΔV = 125 cm^3, k = 0.12 mmHg/cm^3.

In this case, ICP is measured at 7 mmHg after decompressive craniectomy. Assume MAP remains constant throughout.

a) Use the linear model to estimate ICP before surgery, with swelling present.

b) Calculate CPP at baseline, with swelling before surgery, and after surgery.

c) Calculate the percentage change in CPP after surgery relative to both the baseline CPP and the CPP immediately before surgery.



Archaeological finds show that trepanation, the practice of making an opening in the skull, goes back thousands of years.

The surgeon uses a hand-cranked trepan to make the opening while an assistant steadies the patient's head.

This 18th-century engraving from the French *Encyclopédie* shows the operation alongside detailed drawings of other surgical instruments.

Source: *Encyclopédie ou Dictionnaire raisonné des sciences, des arts et des métiers*, "Chirurgie," plate 17 (cropped). Wellcome Collection, 47672i. Public domain.

3) Solutions

a) With swelling before surgery: $ICP \approx ICP_0 + k\Delta V = 10 + 0.12 \times 125 = 25$ mmHg
The model estimates a 15 mmHg rise from baseline.

b) CPP in three states:
- Baseline: CPP = 95 − 10 = 85 mmHg
- Before surgery, with swelling: CPP = 95 − 25 = 70 mmHg
- After surgery (given ICP = 7 mmHg): CPP = 95 − 7 = 88 mmHg

c) Percentage change in CPP:
- Relative to baseline: ((88 − 85) / 85) × 100% ≈ 3.5%
- Relative to preoperative CPP: ((88 − 70) / 70) × 100% ≈ 25.7%

Further Research Questions:

1) What methods are used to measure intracranial pressure clinically?

2) How is the removed skull segment preserved, and when is it replaced?

3) What did the DESTINY II trial [2] find about survival and disability after surgery in patients aged 61 or older?

Table 1) Curriculum Connections

Level	Subject	Relevant Topics	Connection to the Problem
12	Biology	Skull, meninges, CSF, ICP	Swelling in the skull can raise ICP
12	Biology	Stroke, edema, perfusion	Lower CPP can limit blood flow
11–12	Physics	Pressure and volume	Added volume can raise pressure
11–12	Math	Linear models and % change	Model ICP before surgery
Undergrad	Physiol.	CPP and autoregulation	Relate CPP to MAP and ICP
Clinical	ICU care	Severe edema, ICP monitoring	How decompression can lower ICP

References

[1] K. Vahedi *et al.*, "Early decompressive surgery in malignant infarction of the middle cerebral artery: a pooled analysis of three randomised controlled trials," *Lancet Neurol.*, vol. 6, no. 3, pp. 215–222, Mar. 2007, doi: 10.1016/S1474-4422(07)70036-4.

[2] E. Jüttler *et al.*, "Hemicraniectomy in older patients with extensive middle-cerebral-artery stroke," *N. Engl. J. Med.*, vol. 370, no. 12, pp. 1091–1100, Mar. 2014, doi: 10.1056/NEJMoa1311367.



Harvey Cushing (1869–1939) was a pioneer of modern neurosurgery. In 1901, he reported that arterial blood pressure can rise in response to increased intracranial pressure. Photo (1938) from Wellcome Collection via Wikimedia Commons (CC BY 4.0).

Blood Pressure

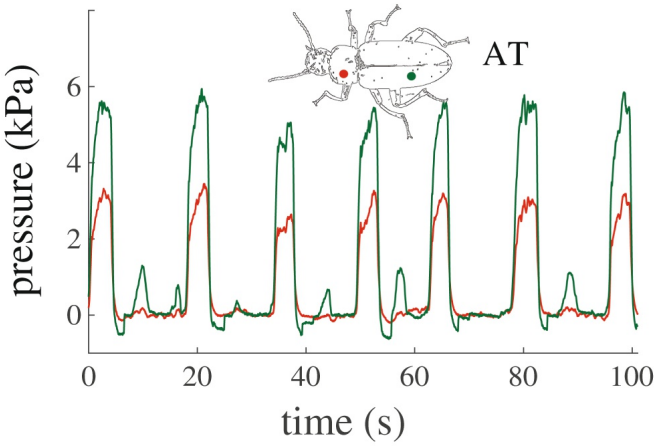
Blood pressure is the force per unit area that blood exerts on the walls of blood vessels. The pressure in an artery rises as the heart pumps blood and falls between beats. The highest pressure in a heartbeat is the systolic pressure. The lowest is the diastolic pressure. A reading of 120/80 mmHg, for example, gives a systolic pressure of 120 and a diastolic pressure of 80 millimetres of mercury. The difference, 40 mmHg in this example, is called pulse pressure [1].

In a manual measurement, an inflatable cuff around the upper arm briefly stops blood flow through the brachial artery. As the cuff deflates, the examiner listens with a stethoscope just below the cuff. Blood first passes through the compressed artery in short bursts, producing tapping sounds called Korotkoff sounds. The cuff pressure when the first repeated taps are heard estimates systolic pressure. The pressure when the sounds disappear estimates diastolic pressure [1].

Blood pressure changes with activity and stress. To compare readings, the person sits quietly with the arm supported at heart level. If the cuff is below heart level, the weight of the column of blood adds to the pressure at the measurement site. Persistently high blood pressure, or hypertension, increases the risk of stroke [1], [2].

Veterinarians and researchers also measure pressure in the circulatory systems of other animals, from mammals to insects. In cats, for example, one common method combines an inflatable cuff with a Doppler ultrasound probe. The cuff can be placed around a foreleg or the tail, and the probe detects blood flow farther down the same limb or tail. As the cuff deflates, the first return of the flow signal marks the estimated systolic pressure. Stress can raise the reading, so the cat is given time to settle [3].

A darkling beetle (*Zophobas morio*) has an open circulatory system. Its circulating fluid, called hemolymph, flows through spaces around the organs. Researchers used two fibre-optic pressure probes, each 0.42 mm wide, to measure pressure in the thorax and abdomen at the same time. Movements of the abdomen can briefly raise local pressure. Recording both sites together shows how the same movement affects the two regions. The graph below shows pressure in kilopascals (kPa). Several peaks in this recording are higher in the abdomen than in the thorax [4].



The graph shows hemolymph pressure recorded simultaneously in the abdomen (green) and thorax (red) of a darkling beetle (*Zophobas morio*). The coloured dots on the drawing mark the locations of the two fibre-optic probes [4].

Pendar et al. [4], Fig. 1C, adapted, CC BY 4.0.

References

[1] P. Muntner et al., "Measurement of blood pressure in humans: A scientific statement from the American Heart Association," *Hypertension*, vol. 73, no. 5, pp. e35–e66, May 2019, doi: 10.1161/HYP.0000000000000087.

[2] Centers for Disease Control and Prevention, "Risk factors for stroke," May 15, 2024. Accessed: Nov. 15, 2026. [Online]. Available: https://www.cdc.gov/stroke/risk-factors/

[3] S. S. Taylor et al., "ISFM consensus guidelines on the diagnosis and management of hypertension in cats," *J. Feline Med. Surg.*, vol. 19, no. 3, pp. 288–303, Mar. 2017, doi: 10.1177/1098612X17693500.

[4] H. Pendar, J. Aviles, K. Adjerid, C. Schoenewald, and J. J. Socha, "Functional compartmentalization in the hemocoel of insects," *Sci. Rep.*, vol. 9, Art. no. 6075, Apr. 2019, doi: 10.1038/s41598-019-42504-3.





Left: A clinician measures systolic and diastolic blood pressure with an upper-arm cuff and a stethoscope [1]. Amanda Mills, CDC PHIL 13512, public domain.
Right: A cuff and a Doppler ultrasound probe are used to estimate a cat's systolic blood pressure [3]. Kalumet, Wikimedia Commons, CC BY-SA 4.0 (cropped).

Statistical Analysis of Stroke Data Based on the Weibull Distribution

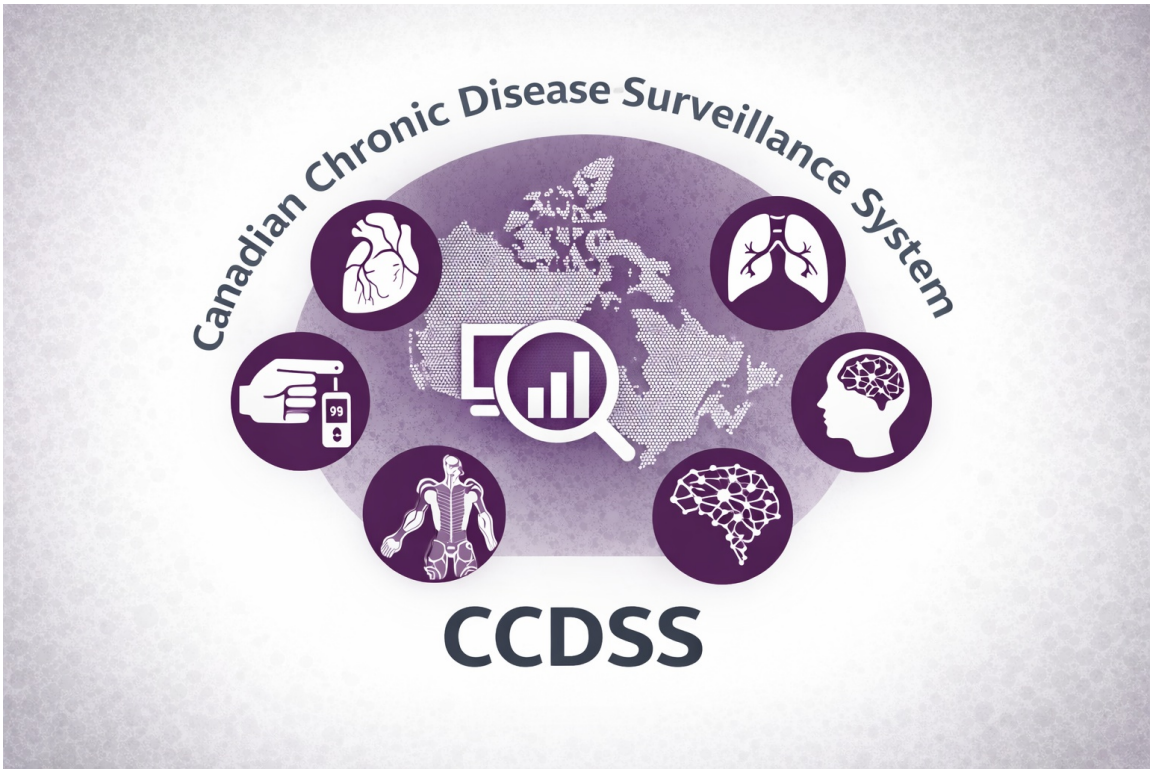
1) Background

The Canadian Chronic Disease Surveillance System (CCDSS) is a national surveillance network supported by the Public Health Agency of Canada. It uses provincial and territorial data to report measures such as incidence and prevalence for chronic conditions, including stroke.

The CCDSS reports stroke incidence by fiscal year and provides national age-specific rates and counts in both five-year and broader age groups.

These data help researchers track changes in population health over time and compare stroke incidence across age groups.

This exercise examines newly identified stroke cases among people aged 20 years and older in the 2023–2024 fiscal year. The CCDSS data for this period exclude New Brunswick [1]. We use the grouped data to estimate the age distribution of reported cases and fit a two-parameter Weibull model.



2) Problem Statement

Table 1 shows the CCDSS stroke incidence rates for the 2023–2024 fiscal year, expressed per 100,000 people at risk in each age group [1].

The final column lists the reported counts of newly identified stroke cases among people aged 20 years and older, with both sexes combined.

Table 1) Stroke incidence by age group

Group	Age Group	Rate	Cases
1	20–24	19	445
2	25–29	22	645
3	30–34	31	985
4	35–39	48	1,450
5	40–44	76	2,170
6	45–49	116	3,010
7	50–54	179	4,460
8	55–59	246	6,230
9	60–64	353	9,455
10	65–69	483	11,415
11	70–74	690	12,990
12	75–79	972	13,925
13	80–84	1,391	12,340
14	85–89	1,852	9,635
15	90+	2,034	7,855

Table 1 shows crude stroke incidence rates per 100,000 people at risk and reported case counts from the CCDSS Age Distribution tab. The data cover fiscal year 2023-2024 in Canada, with both sexes combined. The table includes five-year age groups from 20-24 through 85-89, followed by the 90+ group [1].

Use Table 1 to answer the following questions.

a) For each age group, find the probability that a case falls in that group. Assume the case is selected at random from all cases in Table 1.

b) Draw a bar chart with age group on the horizontal axis and percentage of reported cases on the vertical axis.

c) Let X denote the age in years of a person randomly selected from the reported cases. Estimate the mean and variance of X using the midpoint of each five-year age group and 92 years for the 90+ group.

d) Using part (a), calculate the percentage of reported cases in people younger than each cutoff (25, 35, 45, 55, 65, 75, 85, and 90 years).

e) The density of a two-parameter Weibull distribution is given by

$$f(x) = \frac{k}{\lambda}\left(\frac{x}{\lambda}\right)^{k-1} \exp\left(-\left(\frac{x}{\lambda}\right)^{k}\right), \quad x > 0$$

where λ and k are the positive scale and shape parameters, respectively.

If X has a Weibull distribution, its mean and variance are given by

$$E(X) = \lambda\Gamma\left(1+\frac{1}{k}\right)$$

and

$$\mathrm{Var}(X) = \lambda^2\left(\Gamma\left(1+\frac{2}{k}\right) - \Gamma^2\left(1+\frac{1}{k}\right)\right).$$

The gamma function is defined by

$$\Gamma(\alpha) = \int_0^{+\infty} x^{\alpha-1}e^{-x}dx$$

Using these formulas, estimate λ and k by matching the Weibull mean and variance to the estimates from part (c).

f) Using the Weibull model from part (e), estimate the percentage of reported cases in people younger than each cutoff used in part (d) (25, 35, 45, 55, 65, 75, 85, and 90 years). Compare the results with part (d) and identify the largest absolute difference in percentage points.

g) The Weibull model describes the age distribution of reported stroke cases using two parameters (λ and k). Discuss how grouping ages, choosing 92 years to represent the 90+ group, and using the mean and variance to fit the model can affect its accuracy. Use the comparison in part (f) to judge how well the model describes the reported age distribution. Explain how a fitted distribution can help estimate proportions at ages between the group boundaries.

3) Solution

a) Let case_i denote the reported case count for age group i. The counts in Table 1 sum to $97{,}010$. Group 1 (ages 20–24) contains 445 cases, so the probability that a randomly selected case belongs to this group is

$$\mathrm{P}_1 = \frac{445}{97{,}010} \approx 0.004587.$$

Table 2 gives the probabilities, rounded to six decimal places. For age group i, the calculation is

$$P_i = \frac{\mathrm{case}_i}{\sum_{j=1}^{15}\mathrm{case}_j} = \frac{\mathrm{case}_i}{445 + 645 + \cdots + 7{,}855} = \frac{\mathrm{case}_i}{97{,}010}$$

b) Place the age groups on the horizontal axis and the percentage of reported cases on the vertical axis. Multiply each probability in Column 4 of Table 2 by 100 to obtain its bar height.

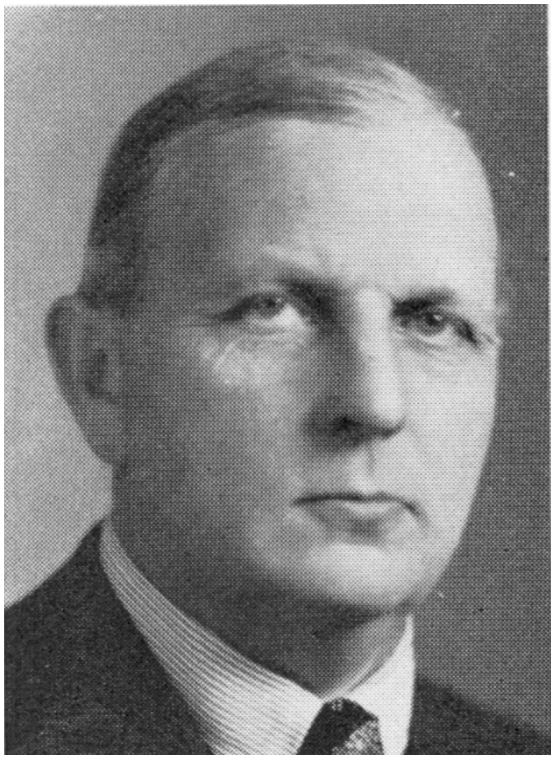
c) Use the midpoint of each five-year age group and 92 years for the 90+ group.
Let $\mu = \mathrm{E}(X)$ be the mean of these ages, weighted by the case counts in Table 2.

$$\mu = \frac{22\times 445 + 27\times 645 + \cdots + 92\times 7{,}855}{97{,}010} \approx 70.7486 \text{ years}$$

$$\mathrm{Var}(X) = \frac{(22-\mu)^2\times 445 + \cdots + (92-\mu)^2\times 7{,}855}{97{,}010} \approx 214.0174 \text{ years}^2$$

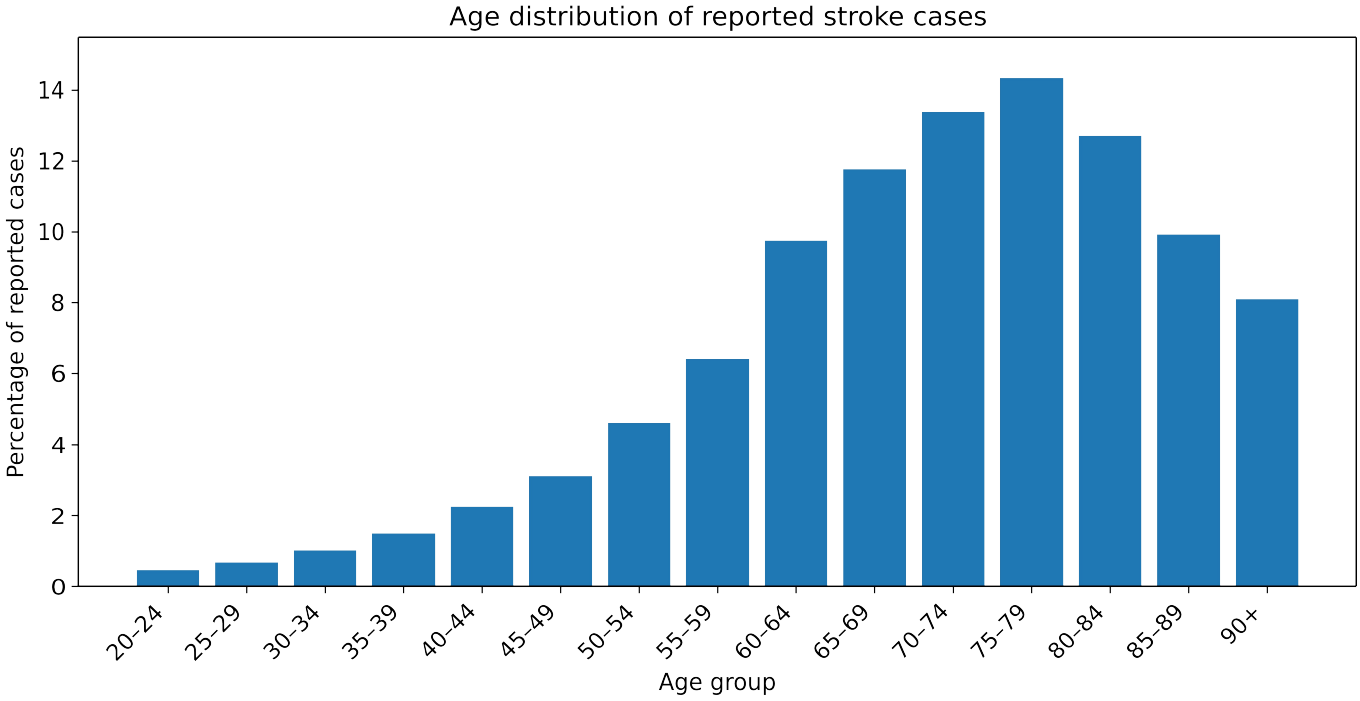
Table 2. Age-group probabilities among reported stroke cases

Group	Age Group	Cases	Probability
1	20–24	445	0.004587
2	25–29	645	0.006649
3	30–34	985	0.010154
4	35–39	1,450	0.014947
5	40–44	2,170	0.022369
6	45–49	3,010	0.031028
7	50–54	4,460	0.045975
8	55–59	6,230	0.064220
9	60–64	9,455	0.097464
10	65–69	11,415	0.117668
11	70–74	12,990	0.133904
12	75–79	13,925	0.143542
13	80–84	12,340	0.127203
14	85–89	9,635	0.099320
15	90+	7,855	0.080971



Ernst Hjalmar Waloddi Weibull
(18 June 1887 – 12 October 1979)

Source: Porträttarkiv (Swedish Portrait Archive), via Wikimedia Commons, licensed under CC BY 4.0.



d) For each cutoff, add the probabilities of the age groups below it. The proportion of reported cases in people younger than 25 is about 0.004587, or 0.4587%. For the cutoff at 35 years, add the first three groups.

$$\frac{445 + 645 + 985}{97{,}010} \approx 2.1390\%$$

The percentages below correspond to the cutoffs of 25, 35, 45, 55, 65, 75, 85, and 90 years, in that order.

$$0.4587\%, 2.1390\%, 5.8705\%, 13.5708\%, 29.7392\%, 54.8964\%, 81.9709\%, 91.9029\%$$

e) Substitute the expression for the Weibull mean into the variance formula.

$$\begin{aligned}\mathrm{Var}(X) &= \lambda^2\Gamma\left(1+\frac{2}{k}\right) - \lambda^2\Gamma^2\left(1+\frac{1}{k}\right)\\ &= \lambda^2\Gamma\left(1+\frac{2}{k}\right) - \mu^2\\ &= \left(\frac{\mu}{\Gamma\left(1+\frac{1}{k}\right)}\right)^2 \Gamma\left(1+\frac{2}{k}\right) - \mu^2\end{aligned}$$

Rearranging and substituting the estimates from part (c) gives

$$\frac{\Gamma\left(1+\frac{2}{k}\right)}{\Gamma^2\left(1+\frac{1}{k}\right)} = \frac{\mathrm{Var}(X)+\mu^2}{\mu^2} = \frac{214.0174 + (70.7486)^2}{(70.7486)^2} \approx 1.042758$$

The ratio from part (e) gives

$$\Gamma\left(1+\frac{2}{k}\right) \approx 1.042758\Gamma^2\left(1+\frac{1}{k}\right)$$

Solving this equation numerically gives $k \approx 5.5909$. Using the mean $\mu \approx 70.7486$ years from part (c), we obtain $\lambda = \frac{\mu}{\Gamma\left(1+\frac{1}{k}\right)} \approx 76.5628$ years.

f) For each cutoff a, the fitted Weibull model estimates $P(X < a)$, the proportion of reported cases in people younger than a.

$$P(X < a) = \int_0^a f(x)\,dx = 1 - \exp\left(-\left(\frac{a}{\lambda}\right)^k\right)$$

Table 3 displays the percentages to two decimal places. Using unrounded values, the largest absolute difference is 4.08 percentage points at the 75-year cutoff.

Table 3. Observed and Weibull cumulative percentages

Age cutoff (yr)	25	35	45	55	65	75	85	90
Observed	0.46	2.14	5.87	13.57	29.74	54.90	81.97	91.90
Weibull model	0.19	1.25	4.99	14.56	32.99	58.98	83.37	91.54

g) Grouping the data hides variation within each age interval. The choice of 92 years for the 90+ group affects the estimated mean and variance used to fit the model. Matching these two estimates can still miss details of the age distribution.

The fit gives broadly similar cumulative percentages at the cutoffs in Table 3. It overestimates the share of cases below the 65- and 75-year cutoffs, where the gaps are largest.

A cutoff at age 73 falls within the 70–74 group. Evaluating the fitted cumulative distribution at that age estimates that 53.52% of reported cases occurred in people younger than 73.

Reference

[1] Public Health Agency of Canada, "Canadian Chronic Disease Surveillance System (CCDSS) Data Tool," *Health Infobase*, 2025. Accessed: Nov. 12, 2026. [Online]. Available: https://health-infobase.canada.ca/ccdss/data-tool/Age?G=00&M=1&V=12

EVERY M1NUTE COUNTS

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