International Standard

ISO 9241-920

Second edition
2024-10

Ergonomics of human-system interaction —

Part 920: **Tactile and haptic interactions**

Ergonomie de l'interaction homme-système —

Partie 920: Interactions tactiles et haptiques

Reference number
ISO 9241-920:2024(en)

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Published in Switzerland

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Foreword

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This document was prepared by Technical Committee ISO/TC 159, *Ergonomics*, Subcommittee SC 4, *Ergonomics of human-system interaction*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 122, *Ergonomics*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition (ISO 9241-920:2009), which has been technically revised.

The main change is as follows:

— The document has been updated to reflect newer research in tactile/haptic interactions.

A list of all parts in the ISO 9241 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Tactile and haptic interactions have become increasingly important interaction modalities. Mobile interaction relies on gesture-based touch interaction and tactile/haptic control devices and can utilize vibration-based displays as one of several ways to provide information or experiences to the user. Touch, vibration and tactile/haptic interactions are also found in special-purpose computing environments (e.g. simulation, remote control or surgery) and in assistive technologies.

While considerable research exists, a lack of ergonomic standards in this area can possibly result in systems being developed without sufficient concern for either ergonomics or interoperability, leading to serious difficulties related to ergonomics for users of multiple incompatible or conflicting tactile/haptic devices or applications.

This document provides ergonomics requirements and recommendations for tactile and haptic hardware and software interactions, including guidance related to the design and evaluation of hardware, software and combinations of hardware and software interactions. The guidelines are not technology-dependent and will also be applicable to future technologies.

ISO 9241-910 provides a common set of terms, definitions and descriptions of the various concepts central to designing and using tactile/haptic interactions. It also provides an overview of the range of tactile/haptic applications, objects, attributes and interactions.

ISO 9241-940 provides ways of evaluating tactile/haptic interactions for their usability, the validation of requirements and the verification that systems meet the requirements.

ISO 9241-960 focuses on gestures as a specific type of tactile/haptic interaction and describes their features and usability requirements. Information on gesture-based interfaces can be found in the ISO/IEC 30113 series. Information on contactless gestures can be found in ISO TS 9241-430.

For guidance and recommendations on the accessibility of tactile/haptic interactions, including information on the use of braille, see ISO 9241-971. It does not provide recommendations specific to braille but can apply to interactions that make use of braille.

Ergonomics of human-system interaction —

Part 920: Tactile and haptic interactions

1 Scope

This document specifies requirements and recommendations for tactile/haptic hardware and software interactions. It provides guidance on the design and selection of hardware, software and combinations of hardware and software interactions, including:

- the design or use of tactile/haptic inputs, outputs and/or combinations of inputs and outputs, with general guidance on their design or use as well as on designing or using combinations of tactile and haptic interactions for use in combination with other modalities or as the exclusive mode of interaction;
- the tactile/haptic encoding of information, including textual data, graphical data and controls;
- the design of tactile/haptic objects;
- the layout of tactile/haptic space;
- interaction techniques.

The recommendations given in this document are applicable to a variety of tactile/haptic devices, representing the real world or virtual or mixed realities (e.g. exoskeletons, wearables, force feedback devices, touchables, tangibles) and stimulation types (e.g. acoustic radiation pressure, electrical muscle stimulation) and they can also be found in virtual and augmented environments.

This document provides general information about how various forms of tactile/haptic interaction can be applied to various user tasks.

This document does not include guidance on the role of walking in virtual or mixed realities for tactile/haptic interaction.

NOTE It is recognized that some interactive scenarios can be constrained by the limitation that a real workspace is to be modelled in a virtual environment. Objects can be in suboptimal positions or conditions for tactile/haptic interaction by virtue of the situation being modelled.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at https://www.iso.org/obp
- IEC Electropedia: available at https://www.electropedia.org/

3.1
electrotactile feedback
delivering tactile/haptic sensations to the user by excitation of the cutaneous nerve fibres with electric current

3.2
electrostatic feedback
delivering tactile/haptic sensations of friction to the user by electric force

3.3
information haptification
presentation and exploration of data and their relations through tactile/haptic interaction

3.4
sensory substitution
information usually analysed by one sense provided through another sense

EXAMPLE 1 Tactile sensations can substitute for visual input, e.g. when visible text is transcribed into tactile sensations through braille for an individual who is blind.

EXAMPLE 2 A visual diagram is substituted by an audible representation of the information in the diagram.

Note 1 to entry: Sensory substitution allows the system to provide the same information in more than one modality. It is not a substitution on the part of human perception. For example, persons who experience synaesthesia, which is an involuntary association of one sense with another or one sensory attribute with another, sometimes experience colour when hearing sound.

3.5
tactile
appertaining to touch

[SOURCE: ISO 9241-910:2011, 2.5]

3.6
haptic, adj
appertaining to *haptics* (3.7)

Note 1 to entry: While there is no difference between haptic and *tactile* (3.5) in most dictionary definitions, in the area of haptics, researchers and developers use haptic to include all haptic sensations, while tactile is limited to mechanical stimulation of the skin. In ISO 9241, the word haptic covers all touch sensations and tactile is used in a more specific manner. Also, both terms can be used together to assist in searches.

[SOURCE: ISO 9241-910:2011, 2.2]

3.7
haptics, noun
sensory and/or motor activity based in the skin, muscles, joints and tendons

Note 1 to entry: Haptics consists of two parts: touch and kinaesthesis.

[SOURCE: ISO 9241-910:2011, 2.1]

4 Applying ISO 9241-920

4.1 Recommendations

The recommendations given in Clauses 5 to 9 should be evaluated for their applicability. The applicable recommendations should be implemented, unless there is evidence that to do so would cause deviation from the design objectives.

4.2 Conformance

If it is claimed that a product conforms to the applicable requirements and recommendations in this document, then the procedures used to establish conformance of the product shall be specified. The level of detail of the specification is a matter of negotiation between the involved parties.

NOTE Guidance on the evaluation of tactile/haptic products can be found in ISO 9241-940.

5 Tactile/haptic inputs, outputs and/or combinations

5.1 General guidance on tactile/haptic inputs, outputs and/or combinations

5.1.1 Optimizing performance

The system should be optimized to take into account the following:

a) the accuracy of available devices, the accuracy of the user and the required accuracy of the task;

b) the ability of a user to control the velocity and the force (including direction) involved in operations;

NOTE 1 High speed of user actions is inconsistent with accurate control of force, and vice versa.

c) active exploration over passive exploration, when appropriate;

NOTE 2 This can increase kinaesthetic perception.

d) extended contact area;

NOTE 3 Extended area can be needed depending on the part of the body in contact with a tactile/haptic device.

EXAMPLE 1 The back does not resolve two-point discrimination as easily as the fingertip.

e) multiple point-of-contact operation, when possible and appropriate;

NOTE 4 This can reduce errors and improve tactile perception.

EXAMPLE 2 The use of two hands in reading braille can improve efficiency.

f) the overall amount and distributed nature of cognitive and sensory task demands.

NOTE 5 Effectiveness of tactile and haptic inputs is affected by overall workload, conflict among multi-task demands and/or overload or decrement of particular sensory information channels.

5.1.2 Providing accessible information on tactile/haptic elements

The system should provide accessible alternatives of all tactile/haptic user interface elements, whether those alternatives are automatically presented or not.

NOTE An accessible alternative can describe the user interface element through text, sound labels, synthetic speech or sign language or as braille text.

EXAMPLE Touchscreen buttons with spoken descriptions.

5.1.3 Providing contextual information

The system should provide a context to help the user to understand the meaning of the tactile/haptic perception and the environment or program.

NOTE 1 Contextual information that is helpful includes information about the purpose of the program, and information about possibilities and pitfalls in the environment.

NOTE 2 Contextual information can be in the form of a short message, such as a caption under an image or model, and presented as speech, sign language or braille.

EXAMPLE 1 An automobile's steering wheel vibrates to provide a tactile cue alert for lane deviation. A visual alert icon on the dashboard simultaneously provides the driver contextual information about why the wheel is vibrating.

EXAMPLE 2 Tactile/haptic cues for presenting information can have an optional auditory cue.

5.1.4 Identifying system state

The system should provide information that allows the user to know which task or function is active.

5.1.5 Minimizing fatigue

The system should:

a) ensure user comfort over extended periods of time;

b) avoid or minimize user fatigue.

NOTE Minimization of tactile/haptic fatigue can be achieved by:

— careful choice of body location for stimulation;

— careful choice of method of contact with the body;

— careful choice of stimulus frequency;

— choosing the lowest effective magnitude of the stimulus;

— reducing minute, precise joint rotations, particularly at proximal segments;

— not using static positions at or near the end of the range of motion;

— not expecting users to overreach to discover the full extent of the display.

5.1.6 Providing alternative input methods

The system should enable users to accomplish the same function in multiple ways. If the task is a fine manipulation task, alternative means should be offered that require less movement precision to enable this type of interaction.

NOTE 1 The most efficient, logical or effective input or control mechanism for a majority of users can potentially be difficult, if not impossible, for individual users with differing abilities to use.

EXAMPLE One-handed (either left or right) operation is used.

NOTE 2 Changing the scale of the virtual environment can make fine motor tasks easier.

5.1.7 Maintaining coherence between modalities

The system should maintain coherence, where appropriate, between the tactile/haptic modality and other modalities, including the descriptions of actions.

NOTE 1 The visual perception of objects can bias, and be biased by, the tactile/haptic perception of objects. This can also occur between the tactile/haptic modality and other modalities.

NOTE 2 Aspects of coherence (amodal attributes) can include:

— size;

— orientation;

— shape;

— mapping;

— separation of objects;

— temporal presentation.

NOTE 3 Coherence also includes the relative location of on-screen controls, including the directions in which they can be moved.

NOTE 4 Incoherence can cause confusion and control instabilities in multimodal systems.

5.1.8 Combining modalities

Combining modalities is recommended, as it supports usability and can make systems more accessible. Some effects of combining modalities are:

a) reinforcement of information obtained from purely tactile/haptic interactions;

EXAMPLE 1 A sound when an object is struck.

b) provision of additional information not presented via tactile/haptic interactions;

NOTE 1 The resulting combinations can enhance spatial memory and the identification and exploration of objects and their attributes.

EXAMPLE 2 Information on the colour of an object.

NOTE 2 Combination of modalities can contradict information obtained from purely tactile/haptic interactions if those modalities present conflicting (i.e. non-congruent) information to the tactile/haptic modality (see 5.1.7).

c) compensation for sensory channels that are diminished or overloaded.

NOTE 3 Tactile cues can be particularly effective when audio or visual cues are less effective (e.g. loud noise, low visibility).

5.1.9 Presenting realistic experiences

While the use of real-world experiences (e.g. following the laws of physics) can enhance the user's understanding, they are not always necessary. Deviating from real-world experiences may be used to:

a) simplify and focus on important features;

b) explore new experiences.

NOTE There are several cases, especially in designing interface widgets, where the slightly unreal, yet well-designed, behaviour of a virtual object makes it easier to use.

EXAMPLE Properties of an object (e.g. size, frequency of its vibration) are changed as it is approached by the user, even though these properties would not change in the real world.

5.1.10 Isolation of individual interface elements

The system should prevent accidental activation of interface elements in proximity to the one being activated.

EXAMPLE 1 Because there is a high risk of unintentional vibration where the nearby actuator vibrates at the same resonant frequency, a rigid surround is installed to reduce the spreading of vibration.

EXAMPLE 2 Mechanical or electrical crosstalk between different tactile/haptic channels is reduced to minimize any unintentional perceptual illusion.

EXAMPLE 3 Active haptic objects that are too close to each other in space results in the user accidentally activating both haptic objects rather than one.

5.2 Intentional individualization

5.2.1 Enabling users to change modalities

The system should enable the user both to disable tactile/haptic output and/or have output presented in another modality, where feasible.

Individuals differ in the ability to effectively perceive, process and use visual, audio and/or tactile/haptic cues. Allowing users the capability to select among alternatives, or combine several modalities when appropriate, should be considered.

NOTE 1 Tactile/haptic stimuli can annoy users who do not want to use them, as they are difficult to ignore.

NOTE 2 Tactile/haptic cues can be preferred when other sensory channels are diminished or overloaded (e.g. loud noise, low visibility, need for stealth).

5.2.2 Enabling force feedback override

The system should allow any force feedback to be overridden by the user.

EXAMPLE When feedback is used for support, the user has the possibility to reduce or stop the feedback if it is no longer felt to be necessary by the user to perform the action or operation.

5.2.3 Force feedback control

Where the system allows force feedback to be disabled by the user, it should be possible to easily reenable it.

EXAMPLE A mobile phone has a "do not disturb" setting that will turn device vibration on or off.

5.2.4 Force feedback indication

Where the system allows force feedback to be overridden by the user, a clear status indicator should be available to support users' awareness of the force feedback state.

5.2.5 Enabling users to limit force feedback

Options to adjust tactile/haptic parameters should be provided to limit the maximum possible force for force feedback to be no greater than the maximum force that the user can exert.

NOTE 1 It can be inappropriate if the delay-time is shorter than the human reaction time.

NOTE 2 Users vary in the amount of force that can overpower or be "too strong" for them.

5.2.6 Enabling users to individualize tactile/haptic parameters

Options to adjust tactile/haptic parameters should be provided to prevent discomfort, pain or injury to users of interactive systems.

NOTE 1 Different users have different thresholds for sensation and pain. Furthermore, over a user's lifespan, thresholds of sensation and pain will change (e.g. spatial and temporal acuity degrade with age).

NOTE 2 Users vary in the amount of maximum force that they can perceive comfortably.

EXAMPLE Tactile/haptic signals are made stronger to overcome distractions and physical exertion.

5.3 Unintentional user perceptions

5.3.1 Limiting acoustic output of tactile/haptic display

Sounds generated as a side effect of the tactile/haptic display should not negatively interfere with:

a) the user perceiving presented auditory information;

b) nearby equipment and/or persons;

c) security requirements;

d) assistive technologies.

NOTE Systems are sometimes designed to use this side effect as part of the experience.

5.3.2 Limiting heat gain of contact surface

The heat gain of the contact surface (not intentionally generated) should not:

a) deform the contact surface;

b) disturb the user's tactile/haptic perception;

c) injure the user's skin;

d) damage the tactile/haptic interface.

NOTE An unintentional temperature increase or decrease of the contact surface of a tactile/haptic interface can occur from various intentional tactile/haptic actions (e.g. vibration, friction) and can affect tactile/haptic perception or action.

5.3.3 Avoiding sensory adaptation

The system should minimize the effects of sensory adaptation to vibration.

NOTE 1 Sensory adaptation effects occur only for vibration stimuli within the same frequency range. One approach to preventing sensory adaptation is to switch between a frequency below 80 Hz and one above 100 Hz. Changes in frequency can change sensation levels. Keeping sensation levels similar can involve adjustments to amplitude in correspondence with adjustments in frequency.

NOTE 2 Sensory adaptation to vibration can decrease a user's absolute threshold and change their experience of subjective magnitude. This is a gradual process caused by prolonged stimulation and can take up to 25 minutes to occur.

5.3.4 Recovering from sensory adaptation

The system should enable the user to recover from sensory adaptation to stimuli.

NOTE A user's recovery time from sensory adaptation to vibration is about half as long as the adaptation time.

5.3.5 Avoiding unintended perceptual illusions

The system should minimize the occurrence of unintended perceptual illusions.

NOTE If stimuli are presented too closely in time and space, the percept can be altered or changed completely. For example, users cannot differentiate two stimuli from each other if they are presented too closely to each other. The stimuli is then perceived, falsely, as one stimulus. However, perceptual illusions are often intended when designing shapes from pins or tactile dots.

EXAMPLE 1 Visual information about the mechanical deformation of a string caused by its simulated stiffness dominates the perception of stiffness and leads to unintended indentation forces.

EXAMPLE 2 Thermal grill illusion is created by altering temperatures between hot (36 °C and 42 °C) or cold (18 °C and 24 °C). This illusion creates the sensation of pain.

5.3.6 Preventing temporal masking

The system should prevent the occurrence of temporal masking.

NOTE 1 Masking can occur when two stimuli are presented at the same location asynchronously.

NOTE 2 Temporal masking can distort the perception of multiple stimuli.

NOTE 3 Presenting stimuli at different locations can prevent temporal masking.

NOTE 4 Presenting stimuli at different frequencies in the same location does not necessarily reduce temporal masking.

6 Attributes of tactile and haptic encoding of information

6.1 High level guidance on tactile/haptic encoding of information

6.1.1 Using familiar tactile/haptic patterns

Where available, well-known tactile/haptic patterns, which are familiar in daily life, should be used for presenting information.

NOTE 1 A person without special knowledge of specialized tactile coding (e.g. braille code, Morse code) will probably be familiar with tactile patterns experienced in daily life.

NOTE 2 Most users are more familiar with tactile/haptic patterns on a surface (embossed or recessed or engraved 2,5D information) or textures or temporal patterns (e.g. vibration).

6.1.2 Making tactile/haptic encoding obvious

Where possible, tactile/haptic encodings should be made obvious to users by ensuring cues are:

a) simple and intuitive;

b) easy to learn and discriminate between.

EXAMPLE Directional cues provided on the body map to real-world directions. For example, to go left, the user gets a vibration on the left wrist or elsewhere on the left side of their body.

6.1.3 Conformity to user expectations

System behaviour should conform to user expectations.

NOTE 1 An object's orientation that does not correspond to the user's expectation can make the object difficult to understand, leading to errors made by the user when manipulating it.

EXAMPLE Predictable behaviour that mimics nature, such as that experienced from gravity, makes control of objects easier.

NOTE 2 User expectations are based on prior experiences in the real or virtual world (e.g. with other similar systems).

6.1.4 Using sensory substitution

When providing sensory substitutions, the system should use the most appropriate sensory substitutions for presenting or receiving the information to or from the user.

NOTE 1 Sensory substitutions can be carried out between modalities that include visual, audio and tactile/haptic.

NOTE 2 When making substitutions, it is important to consider similarities and differences between the senses, utilizing similarities between them and avoiding replacements where the substituting sense is functionally different from the substituted one.

6.1.5 Using appropriate spatial addressability and resolution

The system's spatial addressability and resolution should be appropriate for the task and the user's perceptual capabilities. See also ISO 9241-910:2011, 6.3, for more information on spatial addressability.

NOTE Users will have different perceptual capabilities depending on the body part in contact with the tactile/haptic device.

6.1.6 Using tactile apparent location

Apparent location may be used to increase the spatial addressability of a vibrotactile display.

NOTE Apparent location is the experience of stimulation at a point between two or more actuators.

EXAMPLE Where the task requires access to a greater number of stimulus sites without increasing the number of actuators, the system utilizes apparent location.

6.1.7 Tactile display of high spatial resolution

Where high spatial resolution is needed, the user should interact with the system only with body parts that have a high density of tactile receptors.

NOTE A refreshable braille display uses spatial location as an important parameter in design.

EXAMPLE Fingers and toes are examples of body parts with a high density of tactile receptors.

6.1.8 Using higher addressability for trained users

Where the task allows, displays designed for trained users may use a higher density of stimuli.

NOTE A trained user is not necessarily an expert user.

EXAMPLE People trained to tactilely check the quality of paper are specifically trained to distinguish fine variations in textures.

6.1.9 Using tactile apparent motion

Apparent motion may be used to simulate actual motion.

NOTE 1 Apparent motion is created by perception of multiple consecutive stimuli at one or more loci.

NOTE 2 When using apparent motion, the most important parameters are the duration of bursts and the time intervals between the onsets of the consecutive stimuli.

EXAMPLE 1 In tactile tracking displays, tracks are given apparent motion by displaying consecutive discrete positions.

EXAMPLE 2 Sequential activation of tactors from the back to the front, on a torso display, is a pattern that is used to indicate "move forward".

6.1.10 Preventing spatial masking

The system should avoid spatial masking.

NOTE 1 Spatial masking occurs when one stimulus hides the perception of another stimulus.

NOTE 2 When presenting simultaneous stimuli in different locations, using stimuli with different frequencies (one below 80 Hz and one above 100 Hz) can prevent spatial masking.

6.2 Guidance on specific tactile/haptic attributes for encoding information

6.2.1 Selecting properties for encoding information

Tactile/haptic properties that may be used for encoding information include the following:

a) Material properties:
   1) hardness;
   2) viscosity;
   3) elasticity;
   4) mass or weight;
   5) inertia;
   6) thermal conductivity.

b) Surface properties:
   1) texture;
   2) roughness;
   3) friction;
   4) temperature.

c) Geometrical properties:
   1) size;
   2) shape;
   3) location in environment;
   4) orientation within environment;
   5) spatial pattern;
   6) spatial grating amplitude;
   7) spatial grating frequency;
   8) direction of movement.

d) Temporal properties:
   1) temporal pattern;
   2) temporal vibration amplitude;
   3) vibration frequency;
   4) directional changes of movement.

e) Electrical properties:
   1) electrical waveform;
   2) electrical voltage;
   3) electrical current;

4) electrostatic potential.

NOTE 1 These properties concern the coding of tactile/haptic information used for interaction.

NOTE 2 Electrotactile feedback and electrostatic feedback depend on the electrical waveform and the geometrical dimensions of actuators.

6.2.2 Discriminating between attribute values

Attribute values of tactile/haptic dimensions should be discriminable.

NOTE Material properties, such as texture and hardness, are more salient than geometrical properties, such as size and shape.

6.2.3 Limiting the number of attribute values

Unless it is proven that a user can discriminate between a larger number of values, the number of different values (as for vibration and thermal conductivity) used for encoding any single attribute of a tactile/haptic dimension should be limited to three that are significantly different from one another.

NOTE Although, typically, up to three attributes can be discriminated, a larger number of values can be discriminated for some properties, such as object shape, size, location, texture, temporal pattern and object mass or weight.

6.2.4 Combining properties

Combinations of properties may be used to:

a) encode different information dimensions;

b) encode the same information dimensions redundantly;

c) encode information dimensions that are more complex than the number of allowable values of any of the individual attributes.

6.2.5 Limiting complexity

All purposeful combinations of attribute values within a system should be discriminable.

NOTE When attributes are used in non-redundant combination, the number of discriminable values of an individual attribute can be diminished.

6.2.6 Encoding by object shape

When encoding information by shape, the system should employ shapes the user is familiar with.

EXAMPLE 1 A system uses square, circular and triangular shapes for different types of controls.

EXAMPLE 2 A system with three-dimensional capabilities uses cubes, spheres and cones for different types of objects.

6.2.7 Encoding information by temporal pattern

When encoding information in a temporal pattern, the time between signals should be perceivable and may be adjustable.

NOTE 1 The temporal sensitivity of the skin is very high: 10 ms pulses and 10 ms gaps can be detected.

NOTE 2 Rhythm, tempo and duration can be combined to produce temporal patterns.

6.2.8 Encoding information using vibration amplitude

When encoding information using different discrete vibration amplitude levels, the system should allow the setting of several levels between the detection threshold and the discomfort or pain threshold.

6.2.9 Encoding information by vibration frequency

When encoding information by vibration frequency, the system should:

a) use not more than nine different levels of frequency;

b) use a difference of at least 20 % of the lower frequency between levels;

c) use frequencies between 10 Hz and 600 Hz, unless a lower frequency can be discriminated.

NOTE 1 If presented with the same amplitude, the different levels of frequency mentioned in b) can also lead to different subjective magnitudes.

NOTE 2 There is great variability in how different users experience the sensitivity of the human tactile channel. While the human tactile channel is typically only sensitive to frequencies between 10 Hz and 600 Hz, these thresholds are high, with some users experiencing their lowest threshold at 250 Hz. For the average user, frequencies between 50 Hz and 250 Hz are often preferred.

NOTE 3 Very low frequencies (below 6 Hz) are experienced as a slow motion. Slightly higher frequencies (about 10 Hz to 70 Hz) are experienced as rough or fluttering, while smooth vibration is perceived above about 150 Hz.

NOTE 4 When two or more vibrating stimulators travelling perpendicular to the skin surface operate together to transmit pattern information, a frequency lower than 10 Hz can be applied.

6.2.10 Encoding by body location

When encoding information by body location, the system should take account of the spatial resolution of the body part that is intended to perceive the information.

NOTE 1 Body parts with a high density of tactile receptors have a higher spatial resolution.

EXAMPLE Fingers and toes are examples of body parts with a high density of tactile receptors.

NOTE 2 Using a body joint can increase location identification accuracy.

6.2.11 Encoding by temperature

When encoding information by temperature:

a) the range of temperature values to be used should be well within the comfort limits of the users;

b) the values of temperature used should remain discriminable over the duration of exposure.

6.2.12 Encoding by thermal conductivity

The values of thermal conductivity used should:

a) make due allowance for users' adaptation to them;

b) be generally limited to four in number.

NOTE Thermal conductivity causes a different heat flow rate on the contact surface. Humans usually perceive the rate of heat flow rather than temperature itself.

EXAMPLE Humans feel differences between metal and plastic with the same surface temperature because their thermal conductivities are different.

6.2.13 Identifying information values

When mapping system values to attribute values, the system should aid the user in identifying the values of individual attributes.

EXAMPLE 1 The system provides a set of reference values for identifying roughness.

EXAMPLE 2 The system provides a tactile/haptic symbolic legend for identifying different object types.

6.2.14 Encoding information using electrotactile amplitude

When encoding information using different discrete electrotactile amplitude levels, the system should allow the setting of several levels between the detection threshold and the discomfort or pain threshold.

6.2.15 Encoding information by electrotactile frequency

When encoding information by electrotactile frequency, the system should use frequencies between 2 Hz and 100 Hz, unless a lower frequency can be discriminated.

NOTE 1 Frequencies higher than 60 Hz often cause fast adaptation.

NOTE 2 Frequencies around 10 Hz often cause slower adaptation.

6.2.16 Waveform for electrotactile feedback

When encoding information by electrotactile feedback, the tactile/haptic system should use low-frequency square waves to achieve a more distinct tactile feedback.

NOTE 1 Square wave electrical pulses are more commonly used for electro-neural stimulation than sinusoidal waves due to their improved efficiency and ease of implementation.

NOTE 2 Users of electrotactile devices are more sensitive to stimuli generated by square wave voltage than sinusoidal voltage for frequencies lower than 60 Hz.

6.2.17 Polarity of electrotactile output

As bipolar signals prevent the user from skin irritation due to electrical current, electrotactile feedback should include some depolarisation.

NOTE A delay of between 50 µs and 500 µs can produce delayed depolarisation.

7 Content-specific tactile/haptic encoding

7.1 Encoding and presenting text data

7.1.1 Text presentation speed

The speed of presentation of dynamic text information should be controllable.

The presentation of tactile/haptic text should be designed to support active exploration by the user.

7.1.2 Text presentation layout

The layout of tactile/haptic text presentation should be perceivable and consistent.

7.1.3 Text shape presentation

The shape of a tactile/haptic character should be discriminable.

NOTE Some tactile/haptic characters can be formed by fingers, for example, for communication with deaf-blind people.

7.1.4 Text presentation surface contrast

The tactile/haptic presentation of text should have sufficient contrast.

NOTE 1 Tactile/haptic contrast relates to the perceptual difference between the foreground text and its background surface.

NOTE 2 Height of characters and texture of background can impact discriminability.

7.1.5 Text presentation size

The size of tactile/haptic text characters should be appropriate to the body part intended to decode it.

NOTE 1 See the relevant standards for braille, Moon, Morse code, and raised letters.

NOTE 2 For braille, the dot height, dot diameter, dot distance, character distance, and distance between lines of text are standardized. These braille characteristics are often specified in national standards.

EXAMPLE The fingertip limits the size of braille characters.

7.2 Encoding and presenting data through information haptification

7.2.1 Displaying information in tactile/haptic graphics

Users should be aware of the presence of information haptification.

NOTE Information can be displayed in 2D, 2,5D and 3D.

EXAMPLE Braille characters can be used to create a tactile/haptic bar graph. The design considers the user's awareness that the tactile/haptic rendition is a bar graph and not text.

7.2.2 Complexity of information haptification

Tactile/haptic graphics should be sufficiently simple to be recognized without long exploration.

NOTE 1 Complex figures can be displayed as a set of interlinked figures, where the user is able to go back and forth between figures of low resolution and those of higher resolution that provide greater detail on some portion of the low-resolution figure. An object that is portrayed in its entirety in a low addressability display can then become too large to portray in its entirety.

NOTE 2 Obtaining more detailed information is often achieved by providing the figure with a "zoom" function.

EXAMPLE Tactile/haptic pictures portray only the elements necessary for accomplishing the task(s) for which they are used and avoid using unnecessary details.

7.2.3 Maintaining orientation in information haptification

The user should be supported in knowing where they are in the tactile/haptic environment.

NOTE 1 Appropriate tactile/haptic landmarks can be used as a reference for navigation.

NOTE 2 Knowing where you are is also important when moving between different points or zoom levels.

NOTE 3 One- and two-handed strategies for exploration can be supported at the same time.

EXAMPLE A tactile/haptic system provides an overview-level of the scene or environment, such as a mini-map or different zoom levels. This allows users to explore at one level of detail while having some context of the adjacent features or areas.

7.2.4 Perceivability of information haptification

The important elements of a tactile/haptic graphic should be readily perceived by users of the tactile/haptic display.

NOTE 1 To users without sight, a clear and simple expression of meaning is more important than a high-fidelity version of the presentation.

NOTE 2 Redundant information can be included in the encoding of tactile/haptic symbols of bar graphs to improve accuracy.

7.2.5 Texture discriminability in information haptification

Textures used to convey information should be consistent and easy to discriminate.

7.2.6 Consistency of information haptification

Different uses of information haptification should support different patterns.

7.2.7 Combinations of text and graphics in information haptification

Tactile/haptic text and tactile/haptic graphics should be separated by recognizable gaps.

NOTE 1 The size of the gap depends on the use of lines, textures, the size of the tactile/haptic object and the resolution of the production technology.

NOTE 2 If text becomes too large for presentation within the graphics, a key can be prepared and presented closely with the tactile/haptic graphics on the same page or immediately following the illustration.

EXAMPLE There must be a 3 mm distance between tactile objects produced in swell paper; the distance must be 6 mm if the tactile graphic is printed by a braille printer with equidistant dots.

7.2.8 Learnability of information haptification

Users should be supported in establishing appropriate strategies for exploring different types of information haptifications.

NOTE 1 Some users are limited in the range of different strategies they can use.

NOTE 2 Strategies can be limited by device capabilities (e.g. a device with a single point of contact only allows one-handed interaction).

7.2.9 Using grids on tactile/haptic graphs

Grids on tactile/haptic graphs may be used when exact readings of values are required but should not interfere with the information on the graph. See also 6.2.7.

NOTE Grid lines can be confused with data lines when vision is not available.

7.2.10 Using landmarks in tactile/haptic maps

When appropriate to the use of the map, a tactile/haptic map should emphasize landmarks.

NOTE Landmarks can help the user to become oriented to the content of the map when vision is not present.

7.2.11 Providing scales for tactile/haptic maps

Where distance scales are provided on tactile/haptic maps, they should:

a) be presented in the orientation most relevant to the map contents;

b) make use of scale units that are most easily understandable by the intended user group.

NOTE Units that are relevant to distances between landmarks can be helpful.

7.3 Encoding and using controls

7.3.1 Using tactile/haptic controls

When using tactile/haptic controls:

a) the tactile/haptic controls shall be designed to enable the user to select them without activating their associated functionality;

b) the system should be designed to provide the user with feedback that indicates the selection of a tactile/haptic control and also the activation of a tactile/haptic control.

NOTE Using force effects such as gravity wells or recess effects can improve control discovery and selection.

EXAMPLE 1 Inadvertent activation can be prevented by requiring a minimum force level instead of touch.

EXAMPLE 2 Inadvertent activation of a virtual tactile/haptic push-button control can be prevented by use of an initial springy region where the force increases linearly with displacement, followed by a sudden decrease in resistive force and transition to a deadband where the resistive force is constant, followed by a hard stop where the resistive force approximates that of a hard surface.

7.3.2 Using size and spacing of controls to avoid accidental activation

The system should use sizing and spacing to reduce the likelihood that a user will accidentally activate an adjacent control.

7.3.3 Use of electrodes

Electrodes made of noble metals or conductive polymers can reduce or eliminate any electrochemical reaction due to the electrochemical process for an electrolysis reaction of the skin.

The size of the electrodes should be larger than 10 mm^2. Smaller electrodes can generate higher-density currents and cause discomfort to the user.

7.3.4 Avoiding difficult control actions

The system should avoid using controls that require difficult control actions, such as excessive fine motor precision, awkward limb positions or movements or too-large activation forces.

NOTE Very small controls can require fine motor precision.

7.3.5 Using force to avoid accidental activation

Where avoidance of inadvertent operation is necessary, the operating force should not be too low.

NOTE EN 14366 provides requirements for optimal resistance to the operation of various control types, for example resistance for finger-operated controls can be 2 N to 5 N and for buttons that are operated with fingertips, it can be 2 N.

7.3.6 Support user safety

The system shall be designed to support user safety to avoid any danger from tactile/haptic feedback.

EXAMPLE A device is designed to include a "dead man's grip", which stops the system when the user lets go.

7.3.7 Interacting with virtual controls

The actuating force and torque of virtual controls should not be greater than the maximum values given in Table 1 for physical controls.

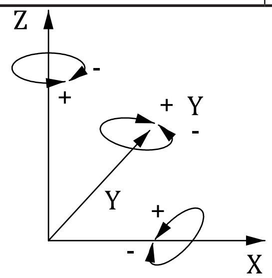
NOTE 1 The maximum force and torque available for use by special populations (e.g. children) can be considerably lower.

NOTE 2 Accuracy and control of movement is reduced the more torque and force are applied.

NOTE 3 The maximum recommended linear actuating force and linear actuating torque is typically lower for operations requiring frequent or sustained exertions, or when the contact area is small (e.g. sharp or pointy surfaces).

Table 1 — Maximum recommended operating forces or torques for manual control actuators

Type of grip	Part of hand applying force	Other factors	Max. recommended linear actuating force N	Max. recommended linear actuating torque N·m
Contact grip	Finger	Any direction	10	0,5
	Thumb	Any direction	10	0,5
	Hand	Any direction	20	0,5
Pinch grip	Finger/one hand	Any direction	10	1
		X direction	10	2
		Y direction	20	2
		Z direction	10	2
Clench grip	One hand	X direction	35	—
		Y direction	55	—
		Z direction	35	—
		0,25 m radius	—	20
	Both hands	0,25 m radius	—	30



SOURCE: ISO 9355-3:2006,[1] Table 4 and Figure 3.

8 Design of tactile/haptic objects and space

8.1 Tactile/haptic display spaces

8.1.1 Ease of perceiving multiple tactile/haptic objects

The system should ensure an easily perceivable presentation of multiple tactile/haptic objects.

NOTE 1 Wearing thin highly elastic materials can increase the resolution of skin receptors, see Reference [29].

NOTE 2 Different parts of the body have different two-point tactile discrimination.

NOTE 3 Generally, multiple contact points and larger contact areas facilitate the perception of multiple tactile/haptic objects.

8.1.2 Ease of identifying adjacent tactile/haptic objects

Where multiple tactile/haptic objects are adjacent, it should be possible to identify them individually and as a group of objects.

NOTE 1 Users can be confused when finding gaps between objects that are intended to be touching each other.

NOTE 2 When many haptically enabled objects are in close proximity, getting to a target can become difficult.

NOTE 3 Different areas of the skin need different distances; for example, within fingertips the minimum distance between tactile symbols is 3 mm, between braille dots typically 2,5 mm and between dotted lines 6 mm.

8.1.3 Maintaining separation between surfaces of objects

Individual objects should be sufficiently separated so that the user is able to perceive the boundaries between them.

NOTE If walls or edges are very close, there is a risk that a finger passing through a wall or edge will also unintentionally pass through an adjacent wall or edge.

8.1.4 Separating tactile/haptic elements

Where not required to be contiguous, tactile/haptic elements should be separated by perceivable spaces.

NOTE Extra spaces between tactile/haptic elements make them more easily perceivable by people with poor tactual sensitivity.

8.1.5 Using consistent labels

Labels of user interface elements that are presented in a tactile/haptic modality that contain the same information or function shall be equal in form, symbol usage and/or text.

8.1.6 Tactile/haptic label design

Labels of user interface elements that are presented in a tactile/haptic modality should:

a) be consistent in size and distances from other tactile/haptic objects;

b) be located according to a consistent rule;

c) be uniformly oriented.

See also 5.1.3.

8.1.7 Avoiding empty spaces

The tactile/haptic space should avoid an excess of “empty space”, as this is a significant source of confusion.

NOTE Empty space refers to areas or volumes on a 2D or 3D display that do not communicate anything useful to the user.

8.1.8 Avoiding volume limits

Restricting surfaces should be used in all directions to avoid tactile/haptic hardware volume limits being mistaken for an object.

NOTE Tactile/haptic clues, such as temporal vibration, can be used to indicate the physical limits of a device. In this way, the device limits will not be confused with objects in the virtual environment.

8.1.9 Avoiding falling out of the tactile/haptic space

Users should not be able to involuntarily “fall out” of the tactile/haptic environment.

NOTE "Falling out" refers to a situation where the user finds themselves outside the modelled virtual space, experiences no feedback and is no longer able to navigate.

8.2 Objects

8.2.1 Using appropriate object size

The size and level of detail of a tactile/haptic object should be appropriate for the task and to the user's perceptual capabilities.

NOTE Objects requiring a large number of points of contact will possibly not be capable of being fully perceived wholly all at once by a user.

8.2.2 Creating tactile/haptic symbols from visual symbols

Tactile/haptic symbols should be chosen for their tactual, rather than for their visual, discriminability.

NOTE 1 There are many symbols that are easy to discriminate visually, while equivalent tactile/haptic symbols can be difficult to discriminate.

NOTE 2 Direct translation from visual to tactile/haptic equivalent form (for use without vision) can be used for simple symbols. However, the more complex the symbol is, the less suitable direct translation can be.

8.2.3 Discriminating tactile/haptic symbols

Tactile/haptic symbols should be easily discriminable.

NOTE 1 Examples of components of symbols that make the symbols difficult to discriminate include:

— small differences in amounts of incline;

— design elements that overlap or have narrow spacing between them;

— reliance on perspective (e.g. three-dimensional objects presented in two dimensions);

— thick lines;

— differing line lengths with different meanings;

— determining parallel lines are parallel;

— large distances between objects;

— small components of symbols that vary slightly between them, e.g. broken lines with small breaks between the dashes, which can be mistaken for continuous lines or continuous straight versus continuously wavy lines, with small amplitude.

NOTE 2 Tactile/haptic cues using multi-tactor simulations of movement can be easily confused, for example short clockwise versus counter clockwise movement around the torso, particularly when the user is moving. Salient pulses at different locations are more easily discriminated.

8.2.4 Tactile/haptic object angles

Tactile/haptic angles and perspectives should be close to those found in the real world.

EXAMPLE Arrowheads can be misinterpreted if they are too wide or too narrow.

8.2.5 Tactile/haptic object corners

When using a single-point interaction style, rounded corners should be used rather than sharp ones.

9 Interaction

9.1 Navigating tactile/haptic space

9.1.1 Providing navigation information

Navigation information support should be available to assist users of tactile/haptic space.

NOTE Providing navigation information keeps users from becoming “lost” in tactile/haptic space.

9.1.2 Supporting path planning

The display should enable the user to plan the shortest path to a target.

9.1.3 Providing well-designed paths

The system should ensure that paths between objects have a clear structure, as well as clear start and end points.

EXAMPLE Easy-to-follow paths are implemented as a small groove or ridge.

9.1.4 Making landmarks easy to identify and recognize

The system should provide well-defined and easy-to-find reference points or landmarks in the environment and ensure that landmarks are easily identifiable and recognizable.

9.1.5 Providing appropriate navigation techniques

The system should provide the most appropriate navigation technique (e.g. stylus, fingertip, multiple fingers, both hands), based on:

a) the target users, domains and task goals;

b) the size of the real or virtual space;

c) the density of objects and their properties;

d) the layout of the tactile/haptic space.

NOTE The available navigation techniques are dependent on the device the system is designed for.