

Human-Factors Reasoning

Ring-scanner program · worn inventory scanner for warehouse pickers

Human-factors engineering document · reasoned against the locked STRIDE form (Krahl, ID concept rev. locked) · Maren Osei, human-factors & ergonomics 28 September 2026

0. What this document is, and how to read the numbers in it

This is the ergonomics case for the physical decisions in the locked design. It is written against the **actual geometry Dieter Krahl locked** — the two-body split, the single-finger saddle, the wedge wrist pack, the flat over-molded bridge, the two triggers, the three-channel feedback stack, the ambidextrous S/M/L strap mount — not against an idealized form. Where the locked form satisfies a human-factors criterion, this document shows the margin. Where it is at or past a limit, this document says so in plain terms so it can be fixed before renders are frozen (see §8, **Open items back to ID**).

Two registers of number appear here, and they are always labeled:

- **Measured data** — anthropometric percentiles and published standard limits. These are real figures from named sources: the **2012 Anthropometric Survey of U.S. Army Personnel (ANSUR II, NATICK/TR-15/007, Gordon et al.)**, **MIL-STD-1472G/H** control-design criteria, **EN ISO 13732-1 / CENELEC Guide 29** contact-temperature limits, **EN 420:2003** glove sizing, and the published spec of the competitive reference set (**Zebra RS5100, ProGlove MARK**). Each is cited where used.
- **Design targets** — numbers this design must hit, reasoned from the measured data (a mass budget, a surface-temperature ceiling, a trigger travel). These are framed as targets, with the reasoning shown, so the engineering team can hold the design to them and verify them on hardware.

Anthropometry note: ANSUR II is a **military** sample and runs larger and leaner at the mean than a general civilian warehouse workforce. Used as a design envelope — 5th-percentile female as the small bound, 95th-percentile male as the large bound — its tails are conservative *for reach and clearance* (the large male hand it describes is at least as large as the civilian one) and slightly generous *for the small end* (a civilian 5th-percentile female hand can be marginally smaller than ANSUR II's). Every small-end fit call in this document therefore carries deliberate margin below the ANSUR II 5th-percentile female figure. Where a civilian-specific figure changes a decision, it is flagged.

The single governing principle, in one line: **carry the mass where the body is built to carry it, put the aimer where the body aims for free, size every touch and every clearance for the gloved hand, and never let one feedback channel carry the confirmation alone.**

1. Anthropometric envelope — the hand this device must fit

1.1 The dimensions that drive the form

Four hand measurements set the geometry of a worn finger-and-hand scanner. Definitions are the ANSUR II landmark definitions so the numbers are traceable:

- **Hand length** — styliion (wrist crease, radial side) to dactylion III (tip of the middle finger), palm flat. Sets how far the wrist pack and bridge run down the back of the hand and where the saddle sits along the index finger.
- **Hand breadth** — across the palm at metacarpale II to metacarpale V (the knuckle line). Sets the width of the back-of-hand pack footprint and the strap span.
- **Index finger length and segment (phalanx) lengths** — set where the saddle seats and how much finger is available fore and aft of the scan window.
- **Wrist (styliion) circumference** — sets the wrist-closure strap range.

1.2 The design envelope (5th-percentile female → 95th-percentile male)

Values below are the ANSUR II summary-statistics register. ANSUR II publishes hand length and hand breadth directly; the finger-segment and wrist-circumference figures are given as the honest working ranges a human-factors engineer carries from the ANSUR II summary report and the Dreyfuss *Measure of Man / Humanscale* tradition, and are labeled as such. Design to the **span**, not to either mean.

Dimension	5th %ile female	50th %ile (F / M)	95th %ile male	Source register
Hand length	≈ 165 mm	172 F / 188 M	≈ 206 mm	ANSUR II summary stats (F mean ≈172 mm, M mean ≈188 mm)
Hand breadth (at knuckles)	≈ 74 mm	78 F / 88 M	≈ 97 mm	ANSUR II summary stats (F mean ≈78 mm, M mean ≈88 mm)
Index finger length (MCP → tip)	≈ 62 mm	~68 F / ~75 M	≈ 82 mm	Dreyfuss/Humanscale working range; ANSUR II hand-length derived
Proximal phalanx, index (seating zone)	≈ 38 mm	~42 / ~46	≈ 52 mm	Working range; sets saddle seat length
Wrist circumference (at styliion)	≈ 150 mm	165 F / 175 M	≈ 195 mm	Working range, Dreyfuss/ANSUR-derived; strap must exceed the large bound gloved

The span this device must accommodate, stated plainly: a hand from roughly **165 mm to 206 mm long, 74 mm to 97 mm across the knuckles**, wearing a glove that adds to every one of those figures (§5), on either the left or the right hand. That is the fit problem the three mount sizes solve (§4).

***Diagram for Anders — "The percentile band."** A single horizontal band per dimension (hand length, hand breadth, wrist circumference), with the 5th-female and 95th-male bounds marked as vertical ticks, the S / M / L mount coverage drawn as three overlapping brackets spanning the band, and the RS5100's single-strap coverage drawn beneath for contrast. The reader should see at a glance that three sizes tile the whole band with overlap, and that no gap in the band is left uncovered.*

1.3 What sets the saddle size — the finger, not the hand

The scan module seats on the **proximal phalanx of the index finger** (between the knuckle and the first joint), which is the shortest, most consistent seating zone available and the one that keeps the module behind the first joint so the finger still flexes and points. The available seating length there runs from roughly **38 mm (5th-percentile female) to 52 mm (95th-percentile male)**. The saddle's rigid seat must therefore be $\leq$ **~34–36 mm long** so it clears the joint creases on the smallest finger, and the loop capture — not the seat length — does the retention. The concept's "low saddle + integrated loop" is the correct architecture for this: the loop adjusts to finger circumference across the range while the seat stays short. **This is a fit requirement the ID must hold: the rigid saddle body cannot grow past ~36 mm along the finger axis without fouling the 5th-percentile female first joint.**

2. Mass distribution — the twelve-hour case for the split

This is Dieter's open question 1, and it is the design's central claim. It is answerable with a moment argument, not an opinion.

2.1 The problem with 70 g on a finger

The **Zebra RS5100 is a single body of 70 g** (measured: Zebra spec sheet, 70 g / 2.47 oz, 61 × 28 × 21 mm), the best single-body ring scanner in the category, and it is genuinely comfortable for a scan. The fatigue problem is not the static weight; it is the **repeated moment about the finger joints across a shift**. The device is cantilevered off the proximal phalanx, and its mass acts at a lever arm from the metacarpophalangeal (MCP) joint. Every time the finger flexes — to point, to grip, to reach into a bin — the small intrinsic muscles of the hand and the flexor/extensor tendons do work against that moment.

At **~8,000 scans per shift** (the concept's stated duty cycle; consistent with the RS5100's own "up to 14,400 scans per battery" register), plus every incidental finger flexion of a picking shift, the finger is not lifting 70 g once. It is managing a 70 g moment through thousands of flexion cycles over twelve hours. That is a

cumulative-load / localized-fatigue problem, and it concentrates in exactly the small muscles least able to sustain it. The RS5100 mitigates it by being as light and low as a full single body can be; it cannot mitigate the fact that the battery, the radio, and the compute are all riding the finger.

2.2 The moment argument for moving the mass

The moment a body part must resist is **mass × the lever arm to the joint that carries it**. Splitting the device attacks both terms:

- **On the finger, we cut the mass.** Body A (saddle: optics, aimer, window, primary trigger, status LED, haptic tap) targets **≤ 22 g** — roughly **a third of the RS5100's 70 g** — precisely because the battery, radio, and main board have left the finger. The finger-borne moment drops by the same ratio, to **~31% of the single-body case**, at the same lever arm.
- **On the wrist, we shorten the lever arm to near zero.** Body B (wrist pack: battery, compute, radio, second trigger, piezo, strong LRA) rides the **back of the hand and cuffs the wrist**, and its mass is **biased rearward toward the wrist (radiocarpal) axis**. Mass carried close to the wrist's own rotational axis, supported by the flat of the back of the hand and the forearm, produces a small moment about a joint (the wrist) that is built to carry load — unlike a finger joint. This is the Dreyfuss principle applied literally: **put the load on the structure evolved to bear it**.

The bridge crossing the knuckle carries **grams of flex circuit and elastomer**, not device mass, so the knuckle itself bears essentially nothing.

2.3 The mass budget (design targets)

Body	Contents	Target mass	Where the moment lands
A — saddle (finger)	optics, aimer, window, primary trigger, status LED, haptic tap	≤ 22 g	proximal phalanx / MCP joint — minimized
B — wrist pack (back of hand + wrist)	hot-swap battery, main board, radio, second trigger, piezo, strong LRA	~55–75 g target range	wrist / forearm — the load-bearing structure
Bridge	over-molded flex circuit	~3–5 g	crosses the knuckle; negligible moment
System total		~80–100 g	distributed, not concentrated

The system's **total** mass will exceed the RS5100's 70 g — a two-body device carries a strap system and a second housing the single body does not. **That is not the fatigue metric and must not be read as one.** The fatigue metric is *where the mass sits relative to the joint that carries it across 12 hours*. On that metric the split wins decisively: it takes the finger from a 70 g cantilever to a ~22 g one and moves the remaining ~55–75 g onto

the wrist/forearm at a near-zero lever arm. **A heavier device that is comfortable all shift beats a lighter one that fatigues the finger by hour eight.** The comparison the client should be shown is not "80–100 g vs 70 g" but "22 g on the finger vs 70 g on the finger" — and that is the honest, defensible headline.

Diagram for Anders — "The moment diagram." Two side-view hand silhouettes. Left: the single-body case — the full 70 g block on the proximal phalanx, a curved arrow showing the moment about the MCP joint, a long red lever-arm line. Right: the STRIDE split — a small ≤ 22 g block on the finger (short lever arm, faint moment arrow) and the wrist pack mass drawn as a block hugging the wrist axis (lever arm collapsed to near zero, moment arrow almost gone). The visual argument: the same job, the moment taken off the finger and given to the wrist. Label the finger-borne mass on each (70 g vs ≤ 22 g) as the real comparison.

2.4 The one honest caveat

The split introduces a load the single body does not have: the **strap contact pressure of the wrist pack on the back of the hand and wrist** across a shift. That is a real fatigue and comfort surface, and it is addressed in §6 (contact pressure) and §3 (thermal). It is a manageable, well-understood problem (every watch, every fitness band, every ProGlove back-of-hand mount lives in this regime) and it trades a *distributed skin-contact pressure* — which the body tolerates for long periods — for a *concentrated joint moment*, which it does not. The trade is correct. It is not free, and this document does not pretend it is.

3. Wrist-pack thermal — the back-of-hand heat case

This is Dieter's open question 3, and it has a hard number behind it.

3.1 The limit is 43 °C, and it is a standard, not a preference

The wrist pack holds the battery, the main board, and the radio against the **back of the hand for a full shift** — a continuous skin contact of many hours over a minor body area ($< 10\%$ of skin surface). The governing limit is **EN ISO 13732-1** (ergonomics of the thermal environment, methods for assessing human responses to contact with surfaces), as tabulated in **CENELEC Guide 29**:

*For a contact period of **8 hours and longer**, the burn-threshold surface temperature is **43 °C** — and for this long duration the threshold converges to 43 °C across materials (metal, plastic, glass, wood alike) for contact over a minor part of the body.*

43 °C is the *burn* threshold. **Comfort** over a shift is lower still: a surface persistently warmer than roughly **body temperature (~37 °C)** against the skin is felt as "warm," reads as a fault, and drives sweat (§3.3). So the design has two lines:

- **Hard safety ceiling: skin-contact surface temperature ≤ 43 °C** at all times, EN ISO 13732-1 8h+ limit. Non-negotiable; this is a safety limit, not a target.
- **Comfort target: skin-contact surface temperature $\leq \sim 40$ °C** sustained, with a design goal nearer $\leq 38\text{--}39$ °C in a normal warehouse ambient ($\sim 15\text{--}25$ °C). This keeps the pack from reading as "hot" and keeps sweat down.

3.2 What that means for the pack — the power constraint

The constraint is on **heat flux into the skin**, which is what the standard's surface-temperature limit protects. The design levers that keep the contact surface under the line are:

1. **Dissipate away from the skin, not into it.** The pack's skin side (against the back of the hand) is the cool side by design; the heat-producing parts (battery under load, main-board regulators, radio PA) sit toward the **outer/upper shell** and shed to warehouse air, which is moving and cooler than skin. The glass-filled nylon shell and the elastomer contact pad both have **low thermal conductivity**, which here is a feature: the elastomer skin-contact pad is a **thermal buffer** that keeps a warm internal surface from coupling straight into the skin.
2. **Keep steady-state dissipation low.** A worn scanner is not a phone under a game load. Its sustained power is radio + standby compute + the trickle of scan-and-decode bursts; the battery's own I^2R heating under a picking duty cycle is modest and intermittent. The design target is to keep **sustained power dissipated at the skin-contact face low enough that, with the elastomer buffer and outward-biased venting, the contact surface holds $\leq \sim 40$ °C in a 25 °C ambient**. The hardware/manufacturing engineer owns the actual thermal budget in watts; this document sets the **surface-temperature ceilings the thermal design must meet** (≤ 43 °C hard / $\leq \sim 40$ °C comfort) and the reasoning behind them.
3. **The hot-swap battery helps thermally, not just for runtime.** A pack sized for a **swappable** cell rather than a heroic all-shift cell runs a smaller, less-stressed battery that is charged off-body in a bay charger, not fast-charged on the hand. On-body charging is the worst thermal case for any wearable; the concept's swap-at-the-cart model **removes the on-body charge heat load entirely**. That is a real thermal win the architecture already banks.

3.3 The cold-storage inversion — and why the pad still matters

A large fraction of warehouse picking, and a stated use case for this device (glove-over-by-default, cold-storage gloves named in the concept), is **cold and freezer work at 0 °C to -25 °C**. There the thermal problem inverts: the device is the *warm* object, and modest waste heat against the back of the hand is **comfort, not hazard** — welcome, even. The 43 °C ceiling is trivially met in the cold. The design consequence is not a heat

problem but a **battery-chemistry and condensation problem** (the pack must run its cell in the cold and must seal against freezer-to-dock condensation cycling — IP65/67 and the sealed over-molded bridge, both already in the concept), which belongs to the hardware engineer. The human-factors point: the elastomer contact pad that buffers heat in a warm DC also **spreads and softens the cold shell against the skin in a freezer**, and its low conductivity slows the cold soak into the hand. The same pad earns its place at both temperature extremes.

Verdict on open question 3: the back-of-hand thermal case is **defensible**, bounded by a named standard (EN ISO 13732-1, 43 °C at 8h+), with a comfort target below it ($\leq \sim 40$ °C), and the architecture already banks the biggest win by moving charging off-body. The constraint the hardware team must design to is stated: **contact-surface temperature, not internal temperature, is the limit, and 43 °C is the wall.**

4. The three mount sizes — S / M / L, ambidextrous

This is Dieter's open question 4. The job of the sizing strategy is to tile the anthropometric band of §1 with **three shell sizes plus adjustment**, for both hands, with no one left outside the band.

4.1 Why three sizes and not one adjustable strap

A single strap can adjust *circumference* (wrist and finger loop) across a wide range. It cannot adjust the **rigid footprint** of the back-of-hand pack or the **span between the finger loop and the wrist cuff** — those are set by the shell, and they must match hand *length* and hand *breadth*, which vary by ~ 40 mm and ~ 23 mm respectively across the design band (§1.2). Put the M pack on a 5th-percentile female hand and the wrist cuff lands too far down the forearm and the pack overhangs the hand's edges; put the M pack on a 95th-percentile male hand and the cuff rides above the styloid and the finger loop pulls short. **Three shell sizes size the rigid geometry; the straps and loops adjust the soft circumference within each.** This is exactly why the reference set (RS5100 hand mounts, ProGlove) ships multiple mount sizes rather than one.

4.2 The size bands (design targets, built on ANSUR II)

Each size covers a contiguous slice of hand length / breadth, with **deliberate overlap** at the boundaries so a hand near a seam fits either neighbor and no one falls in a gap. The straps extend each size's *circumference* range further; the shell sizes below are set by *length and breadth*.

Mou nt	Hand length covered	Hand breadth covered	Approx. percentile span (mixed F+M)	Wrist strap range (must reach, gloved)
S	~160–178 mm	~72–82 mm	5th %ile female → ~40th %ile	to ~155–180 mm circ., gloved
M	~174–192 mm	~80–90 mm	~35th %ile → ~80th %ile (the mode)	to ~170–200 mm circ., gloved

Mou nt	Hand length covered	Hand breadth covered	Approx. percentile span (mixed F+M)	Wrist strap range (must reach, gloved)
L	~188–208 mm	~88–98 mm	~75th %ile → 95th %ile male	to ~185–215 mm circ., gloved

Coverage check. S's lower bound (~160 mm length, ~72 mm breadth) sits **at or below the ANSUR II 5th-percentile female** hand (~165 mm / ~74 mm), with margin for the civilian small tail flagged in §0. L's upper bound (~208 mm / ~98 mm) sits **at or above the ANSUR II 95th-percentile male** (~206 mm / ~97 mm). The three bands overlap by ~4 mm at each seam. **The band of §1.2 is tiled end to end with no gap.** That is the sizing requirement met.

4.3 Wrist-strap range is the separate, harder number

Hand length and breadth set the shell; **wrist circumference sets the strap**, and the strap must close on the *smallest* wrist and still reach around the *largest gloved* wrist. Wrist circumference across the design band runs roughly **150 mm (5th-percentile female) to 195 mm (95th-percentile male)** bare; a warehouse or cold-storage glove and cuff adds meaningfully to the large end. The cam-and-hook-and-loop closure the concept specifies is the right mechanism precisely because it gives a **long continuous adjustment range** rather than discrete holes — so each shell size's strap spans its wrist band and overshoots the gloved large end.

Requirement to ID/engineering: each size's wrist strap must close fully on that size's small bound AND reach around that size's large bound plus a cold-storage glove cuff (add ≥ 15–20 mm over the bare figure). Verify the L strap on a 95th-percentile male wrist over a freezer glove — that is the worst case and the one that strands a picker if it is short.

4.4 Ambidextrous — one product, either hand

The concept makes left/right a **strap flip and a saddle-trigger rotation, not a second SKU**. This is correct and it is table stakes (the RS5100 is ambidextrous by the same logic). The human-factors requirements the symmetry must actually meet:

- The **saddle trigger must rotate to either flank** so it falls under the thumb of whichever hand wears it (a right-hand wearer's thumb is on the left flank of the index finger; a left-hand wearer's is on the right). The concept specifies this.
- The **wrist-pack second trigger and the LED bar must be readable and reachable in both mirror orientations**. A pick-path LED bar that means "turn left" must map correctly when the pack is flipped; this is a firmware/marketing concern flagged here so it is not missed.
- The **pack footprint must be symmetric** (no asymmetric cutout that only clears the thumb on one hand). The wedge section is symmetric about the metacarpal axis, which satisfies this.

Verdict on open question 4: three shell sizes plus cam-strap adjustment cover the ANSUR II 5th-female → 95th-male band for both hands with overlap and no gap, provided the L wrist strap is verified over a cold-storage glove at the 95th-percentile male wrist. That verification is the one live item and it is called out in §8.

5. Glove-first — touch targets, actuation, and why the feedback is triple

This is Dieter's open questions 2 and 5, taken together, because glove-first is what shapes both the triggers and the feedback.

5.1 The gloved hand has lost the senses the design cannot assume it has

A warehouse or cold-storage glove — the concept's default wear — does three things to the hand that drive every touch decision:

1. **It enlarges the digit.** A gloved finger and thumb are larger in cross-section; every clearance and every seating channel must fit the gloved digit, and the bare-hand fit becomes the *small* end of the range, not the design point.
2. **It kills fine proprioception and tactile edge-finding.** A gloved thumb cannot feel a flush button's edge, cannot feel a shallow detent, and cannot place itself precisely by touch. Targets must be **large, proud, and edge-defined** so the thumb finds them by gross feel, not fine feel.
3. **It dulls light vibration.** A thin or a weak haptic buzz felt fine on bare skin can be **undetectable through an insulated cold-storage glove** on a cold hand. This is the single most important fact behind the three-channel feedback stack (§5.4).

5.2 Trigger sizing and force — the numbers, from MIL-STD-1472

The governing control-design standard is **MIL-STD-1472G/H** (DoD Design Criteria Standard: Human Engineering), which tabulates pushbutton and control dimensions for **bare vs. gloved** operation. The relevant figures:

Parameter	MIL-STD-1472 bare hand	MIL-STD-1472 gloved hand	STRIDE trigger target
Fingertip pushbutton, min diameter	10 mm	19 mm	—
Thumb pushbutton, min diameter	19 mm	25 mm	≥ 20 mm effective, paddle-style
Separation, single-finger, min	13 mm	25 mm	two triggers well separated (finger vs pack)
Actuation force (single finger)	2.8 N min	up to ~11 N max	~3–6 N, with detent
Access to first joint, pushbutton	32 mm	38 mm	clearance around trigger sized gloved

Corroborating civilian register: **ISO 9241-9** industrial gloved touch-target guidance gives **20–25 mm minimum, 25–40 mm ideal** for gloved operation — consistent with MIL-STD-1472's gloved figures. Both point the same way.

What this means for the two triggers:

- The triggers are **large, proud paddles, not flush buttons**. MIL-STD-1472's gloved thumb minimum is 25 mm for a discrete pushbutton; a **paddle** (the concept's chosen form) satisfies the "found by gross feel" requirement even better than a round button because its **raised rim and long edge** are findable across a wider search area. The concept's "softly proud, edge-defined, gloved-thumb-findable" language is exactly right and is met by the paddle form.
- **Actuation force ~3–6 N with a positive tactile detent**. Below MIL-STD-1472's ~2.8 N floor the trigger fires on incidental contact (false scans, a real cost at 8,000 intentional scans/shift — every accidental fire is a mis-scan to chase down); a hard detent well above that floor but well below the ~11 N fatigue ceiling gives a **felt "click" through the glove** so the picker knows the scan fired without watching. The detent is a fourth, mechanical confirmation channel at the trigger itself, and it costs nothing.
- **Travel long enough to feel through a glove**. A gloved thumb needs a few millimeters of travel to register the press; the paddle should give ~**2–4 mm** of felt travel to the detent, at the upper end of MIL-STD-1472's fingertip displacement range, because the glove eats the low end.

5.3 Reach envelope — the two triggers answer two different hand states (open question 2)

The design has two triggers on purpose, and the reason is a **reach-envelope** argument. The picker's hand is not always free.

- **Finger-saddle trigger — thumb-over-curved-index**. With the hand in a relaxed point or a light grip, the **thumb naturally falls onto the flank of the index finger's proximal phalanx** — exactly where the saddle trigger sits. This is the fastest, most natural fire and it is a **short, in-envelope thumb excursion**: the thumb tip reaches the side of the index finger's base with essentially zero wrist movement across the whole hand-size band. For the 5th-percentile female hand the thumb still reaches (shorter thumb, but the target is on the adjacent finger, the closest possible control); for the 95th-percentile male hand there is ample reach. **The saddle-trigger reach is in-envelope for the entire design band**. The requirement is that the trigger sit on the flank the thumb can reach — which is why it must rotate for left/right (§4.4).
- **Wrist-pack trigger — for when the hand is full**. When the fingers are **wrapped around a heavy box or a bin**, the index finger cannot extend to aim *and* the thumb cannot always reach the saddle trigger past the load. The second trigger, on the **thumb-side edge of the wrist pack**, is reachable by (a) the **same hand's thumb** brought back to the wrist even with the fingers loaded, or (b) the **opposite hand**. This is the "keep scanning with a full hand" case, and it is a real one on a picking floor. Its reach requirement is looser (the thumb-to-wrist-edge or opposite-hand path is generous), but the trigger must sit on the pack edge the thumb sweeps to, mirrored correctly for left/right.

Diagram for Anders — "The reach envelope." A top-down hand with the index finger wearing the saddle. Draw the thumb's reach arc as a shaded wedge; show the saddle trigger sitting inside the arc at the index-finger flank (labeled "natural point / light grip — primary"), and the wrist-pack trigger sitting where the thumb sweeps back to the wrist (labeled "hand full — secondary"). A small inset showing the same hand wrapped around a box, with the finger trigger unreachable (greyed) and the wrist trigger lit, makes the two-trigger logic obvious in one look.

5.4 Why three feedback channels — each environment defeats a different one (open question 5)

This is the heart of the glove-first case and the redundancy is not belt-and-suspenders caution; it is a **specific-failure-mode** argument. The warehouse defeats each single channel in a specific, nameable way:

Channel	What it is (per concept)	What defeats it	Why the other two survive that
Audible	piezo beeper in pack, distinct good/error tones, target ≥ 90 dB at the ear	Ambient noise — conveyors, forklifts, HVAC, a busy DC runs 80–90 dB; ear protection is common	Haptic and LED do not depend on hearing
Haptic	strong LRA in the wrist pack, single tap good / double-tap error, fired into the wrist	A thick cold-storage glove on a cold hand dulls light vibration; also a distracted, moving picker	Beep and LED do not depend on skin sensation
Optical (LED)	bright status LED on the saddle (in the aim sightline), LED bar on the pack	A glance away — the picker looks at the shelf, the tote, the next bin, not the device	Beep and haptic do not depend on looking

Read the table as the design argument: **noise defeats the beep, the glove-and-cold defeats the haptic, looking-away defeats the LED — and no two of those failures usually coincide, so any two channels back up the one the environment killed.** That is why the design refuses to confirm a scan on a single channel. This is the correct human-factors posture for a device that must confirm ~8,000 reads/shift in a hostile sensory environment, and it is why the concept's three-channel stack is not over-engineering — it is the minimum defensible redundancy.

Three requirements the stack must meet to actually deliver this:

- The haptic must be strong and pack-mounted, not finger-mounted.** A tap fired into the **wrist** transmits through the wrist and forearm and is felt through a glove; a light tap on the fingertip is exactly what the glove kills. The concept places the strong LRA in the pack — correct. (The saddle's small haptic tap is a secondary "aim confirmed" nicety, not the read-confirm channel.)
- The beeper must clear real ambient noise.** The RS5100's beeper is **up to 85 dBA at 10 cm** (measured, Zebra spec). A busy DC ambient at the ear is 80–90 dB. The concept's **≥ 90 dB target** is the right call — it must be *louder than the reference* to be reliably heard, with **distinct good vs. error tones**

(a frequency/pattern difference, not just a volume difference, so it reads through hearing protection) and a **settable/mutable volume** for quiet-hours or noise-restricted facilities.

3. **Good and error states must differ on every channel, not just one.** Good = single haptic tap + rising tone + green LED; error/no-read = double-tap + distinct error tone + red LED. A picker must be able to tell a good read from a no-read on **whichever single channel is currently getting through** — the redundancy only works if each channel independently carries the good/error distinction.

5.5 Donning / doffing and hygiene

- **Donning target: under ~15 seconds, one-handed-assisted, gloved.** The picker slides the hand into the mount, closes the cam wrist strap, and is scanning. The cam-and-hook-and-loop closure is workable by a gloved hand (large pull tab, no fine pinch) — the concept's amber strap pull-tabs are the findable grab point. **Requirement: the strap must be closable and releasable by a gloved hand with no fine-motor pinch.** Verify on a gloved 5th-percentile female hand (smallest grip strength / shortest reach across the strap).
 - **Doffing for a swap: the battery swaps without doffing** (concept's slide-and-latch at the cart, ~10 s) — the wearable stays on. Full doffing at shift end is the reverse of donning.
 - **Hygiene for shift-rotated / shared units:** the concept makes the **mount the launderable, replaceable, sweaty part** and the electronics the part that stays. This is the correct hygiene architecture: the soft goods that touch skin and absorb sweat are **removable and washable/replaceable per worker or per shift**, and the hard shells (saddle, pack) wipe down. For shared-pool devices this matters — a worn strap is a hygiene item, not a warranty return. **Requirement flagged: specify the strap set as cleanable/laundryable to a stated cycle, and size the mount SKUs so a facility can pool electronics and issue personal straps** (the cheapest, cleanest operational model).
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6. Twelve-hour fatigue — the whole-shift synthesis

This is Dieter's open question 6, and it pulls the threads above into the single question that matters: **is this device comfortable and safe for a real 12-hour picking shift at ~8,000 scans?** The answer is built from four load surfaces, each with its mitigation already in the locked form.

6.1 The four fatigue surfaces

1. **Finger joint moment (repetitive load).** Addressed in §2: the finger carries ≤ 22 g, ~31% of the single-body case, at the same lever arm — the dominant fatigue driver of a ring scanner is cut to a third. This is the biggest single win and it is the reason the architecture exists.
2. **Wrist-pack contact pressure (sustained static load).** The pack's mass is carried on the **flat of the back of the hand and the wrist** through the strap. The comfort requirement is to **spread that contact**

pressure over the largest practical area so peak pressure stays low, and to **bias the mass rearward toward the wrist** (concept: thin-at-knuckles / thick-at-wrist wedge) so the load sits over the forearm's support, not out on the hand. Contact pressure — not a sharp point load — is what the body tolerates for hours; the elastomer underside (60–70 Shore A, high friction) both spreads the pressure and stops the pack **migrating** on the hand across a shift (migration is a real fatigue and re-seating nuisance). **Requirement: no hard-shell edge bears directly on the back of the hand or the styloid; every load-bearing contact is through the compliant elastomer, and the strap tension is spread by a broad cuff, not a narrow band.**

3. **Thermal load (sustained).** Addressed in §3: contact surface $\leq 43^{\circ}\text{C}$ hard / $\leq \sim 40^{\circ}\text{C}$ comfort, with on-body charging removed by the swap architecture. A hand kept dry and near-neutral in temperature does not fatigue from the device thermally.
4. **Sweat and skin maceration (sustained, warm-DC case).** A mount worn 12 hours in a warm DC sweats. The mitigations: the **elastomer contact surfaces are chosen to hide and shed sweat-sheen** (concept, cool-grey elastomer), the **mount is the launderable part** (§5.5), and — a requirement to flag — the **skin-contact soft goods should breathe** where they can. A fully sealed elastomer pad against the palm-side/back-of-hand traps sweat; a **perforated or textile-backed contact layer** on the non-structural areas lets the skin breathe while the sealed electronics stay IP-rated. **Requirement: separate the sealing surface (must be IP65/67, solid) from the skin-comfort surface (should breathe) — do not make the whole back-of-hand contact one impermeable pad.**

6.2 Repetitive-motion load over ~8,000 scans

The scan action itself is a **thumb press** (finger or pack trigger), not a finger-flex, once the device is donned — the aiming is done by the naturally-pointing index finger the picker already uses, and the **fire is a low-force thumb detent (~3–6 N)**. Eight thousand thumb presses at ~3–6 N against a well-placed, well-detented paddle is a **modest, in-envelope repetitive load** — far below the injury regime of a high-force or awkwardly-placed trigger. The two things that would turn this into a repetitive-strain problem, and how the design avoids them:

- **A too-stiff trigger** ($> \sim 11$ N, MIL-STD-1472 ceiling) turns 8,000 presses into a cumulative overload. **Target ~3–6 N keeps it well under.**
- **An out-of-envelope reach** (a trigger the thumb must stretch or the wrist must contort to reach) turns each press into an awkward-posture cycle. **The saddle trigger sits under the naturally-falling thumb (§5.3) — the shortest, most neutral thumb excursion available.** This is the key: the design puts the repeated action in the **most neutral posture the hand offers**, so 8,000 repetitions accumulate the least possible load.

The **hands-free between scans** is itself the biggest repetitive-motion mitigation: the picker's hands are free to grip, lift, and move product with the device worn but not held, so the hand is not locked around a scanner all shift (the handheld-scanner failure mode). The worn architecture is what makes the whole picking motion

natural; the scanner rides along and fires on a light thumb press.

6.3 The whole-shift verdict

Assembled, the case is: **the dominant fatigue driver (finger moment) is cut to a third; the residual mass sits on the wrist/forearm where the body carries load; the thermal and sweat loads are bounded by a named standard and the swap architecture; the repeated action is a light, well-placed, well-detented thumb press in a neutral posture; and the hands stay free to work.** Every one of those is a decision already in the locked form. The device is defensible for a 12-hour, ~8,000-scan shift — **more defensible than the 70 g single body it is measured against**, on the metric that actually governs shift fatigue (finger-borne moment), with the honest cost (wrist-pack contact pressure and sweat) named and mitigated rather than hidden.

7. Standards and sources — the register behind every number

Everything load-bearing in this document traces to one of these. Where a figure is a reasoned *target* rather than a *measured* value, it is labeled as such in the text above.

- **ANSUR II — 2012 Anthropometric Survey of U.S. Army Personnel: Methods and Summary Statistics**, Gordon, C.C. et al., NATICK/TR-15/007 (2015). Hand length (stylion → dactylion III), hand breadth (metacarpale II–V), and the full percentile summary. Sample: 4,082 men, 1,986 women. *Caveat carried in §0: military sample, larger/leaner than civilian at the mean; used here as a conservative design envelope with margin added at the small end.*
- **MIL-STD-1472G / MIL-STD-1472H — DoD Design Criteria Standard, Human Engineering.** Pushbutton and control dimensions, bare vs. gloved (fingertip 10 → 19 mm, thumb 19 → 25 mm, single-finger separation 13 → 25 mm, access-to-first-joint 32 → 38 mm gloved), actuation force (2.8 N floor, ~11 N ceiling), displacement.
- **ISO 9241-9 (industrial gloved touch-target guidance)** — 20–25 mm minimum, 25–40 mm ideal for gloved operation. Corroborates MIL-STD-1472's gloved figures.
- **EN ISO 13732-1 (ergonomics of the thermal environment — contact with surfaces) / CENELEC Guide 29.** Prolonged-contact (8h+) burn threshold **43 °C**, converging across materials for a minor body area. The wrist-pack skin-contact ceiling.
- **EN 420:2003 — protective gloves, general requirements & sizing.** Glove size vs. hand circumference/length (size 6 = 152 mm circ. / 160 mm length ... size 11 = 279 mm / 215 mm). Sets the gloved-hand enlargement the fit must absorb.
- **Zebra RS5100 published specification** (Zebra spec sheet / product reference guide). Measured: **70 g**, 61 × 28 × 21 mm, single-finger ambidextrous trigger, **beeper up to 85 dBA @ 10 cm**, 4 RGB LEDs, IP65,

0–50 °C operating, 480 mAh (up to ~14,400 scans / ~12 h). The single-body reference this design is argued against.

- **ProGlove MARK** — back-of-hand mounted worn scanner, ~40 g class, cited as the "aim-from-the-hand" alternative the split refuses to trade into (loses fingertip aim). Used qualitatively.
 - **Henry Dreyfuss, *The Measure of Man and Woman* / Humanscale tradition.** The design-envelope method (5th-female → 95th-male), the "carry load on the structure built for it" principle, and the finger-segment/wrist working ranges labeled as such in §1.2.
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8. Open items back to ID and engineering — the live verifications

Everything above is defensible on the locked form. These are the **specific things to verify on hardware or resolve in the ID before renders freeze** — the honest live list, not a hedge:

1. **Saddle rigid-body length $\leq \sim 36$ mm along the finger axis** (§1.3). The rigid seat cannot foul the 5th-percentile female first joint. Confirm the locked saddle geometry against this — it is the one fit dimension that bites the small hand.
2. **L wrist strap over a cold-storage glove at the 95th-percentile male wrist** (§4.3). The one live sizing item. Verify the strap fully reaches the largest gloved wrist; a short strap strands a picker. Add ≥ 15 –20 mm over the bare figure.
3. **Wrist-pack contact-surface temperature ≤ 43 °C hard / $\leq \sim 40$ °C comfort in a 25 °C ambient** (§3). Hardware/manufacturing engineer owns the watt budget; this document owns the surface ceiling. Verify on a thermal mock-up under a realistic picking duty cycle — the limit is *surface temperature at the skin*, not internal temperature.
4. **Separate sealing surface from breathing surface on the back-of-hand contact** (§6.1). Do not make the whole skin-contact pad one impermeable slab; the IP-sealed surface and the skin-comfort surface are different jobs. Flag to ID for the contact-pad detail.
5. **Trigger force ~ 3 –6 N with a positive detented click, felt through a glove** (§5.2). Verify both triggers on a gloved thumb — the detent is the mechanical confirm channel and must be felt, not just measured.
6. **Ambidextrous LED-bar mapping when the pack is flipped** (§4.4). Firmware/markings: a "turn left" indication must stay correct in the mirrored (left-hand) orientation. Not a form issue, but it lives in this document so it is not lost between ID and firmware.
7. **Haptic strength verified through a cold-storage glove on a cold hand** (§5.4). The whole three-channel argument rests on the pack haptic being felt through a freezer glove. Bench-verify the LRA amplitude against a real cold-storage glove, cold — the worst case — not a bare hand.

None of these is a defect in the locked form. Each is a number to confirm on the way from concept to production, and each is stated concretely enough to close.

This document is the human-factors case for the physical decisions in the locked STRIDE form. Every percentile, standard limit, and reference-device figure is traceable to §7; every design target is labeled as a target with its reasoning shown. Where the form is at a limit, §8 says so. The design is defensible.