Physical Augmentation Concept for Improved Soldier Lethality

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Small Arms Interface Reimagined

- *Traditional interface is a limiting factor for achieving battlefield dominance*

Overmatch in small arms (SA) engagements

- *SA are the most fielded weapon systems*
- *No overmatch: since end of WWII, US lost ~ 60,000 soldiers to SA fires*
- *Modern body armor: survivability improvement, with trade-offs (decreased mobility, adversaries also have access)*
- *Most SA combat within 200 m in urban terrain, most within 50 m*

Requirements for Achieving Overmatch

- *High P(H)—probability of hit*
- *Improved lethality through barriers via improved impact kinetic energy (KE)*
- *Compact weapons for confined spaces*
- *Reduce Soldier burdens while increasing Soldier lethality*
- *Intuitive interface for rapid time-to-target engagement*
- *Firing posture stabilization*
- *Weapon weight and recoil redistribution*

"Field Tested" Weapons

- ***Pistols***
  - *Compact, can carry everywhere*
  - *Pathetic ballistics (~ 500 J KE at muzzle)*
  - *Degraded P(H)—probability of hit*

- ***Rifles/Carbines***
  - *Improved effective range*
  - *Not compact, burden to carry*
  - *Barely acceptable ballistics*
  - *Poor performance through many barriers*
  - *P(H) poor for rapid/fleeting targets and at extended ranges*

- ***Ammo***
  - *Presently, KE not high enough: higher KE = longer, heavier gun*
  - *"Future" caliber studies: scaled up/down variants of 7.62 mm projectiles*

~ 1895, 7.62x54mmR

~ 1943, 7.62x39mm

~ 1974, 5.45x39mm

~ 1954, 7.62x51mm

~ 1963, 5.56x45 mm, M193

~ 2009, 5.56x45mm M855A1

"Field Tested" Human-Weapon Interface

- ***Soldier's weapon interface unchanged since the crossbow.***
- ***Poor P(H) for rapid/fleeting targets and at extended ranges.***
- ***Field tested weapons have been developed over human history.***
- ***At what point does "field tested" mean "idea stagnation"?***

Gun Propulsion – greater performance in smaller packages

- *ARL "Advanced Kinetics"*
  - *Muzzle Velocities well over 4000 fps*
  - *Very high impact KE from carbine-sized weapons*
  - *Subcompact weapons: 12-18" in overall length*
  - *Impact energies > 7.62 mm NATO (typically 40+ inches in overall length)*

Human/Machine Interface – play to each other's strengths

- *Improved visual processing for machines based on human visual search (Butko & Movellan, 2009)*
- *Goal-directed motor behavior modeling using movement primitives (Ijspeert et al., 2013)*

Vision: Compact weapons, new human interface = performance benefits for mobility, short/long-range target engagement, terminal ballistics

Benefits of high-performance weapon concepts

- *High P(H)—probability of hit*
- *Low engagement times*
- *Improved terminal effects*

Potential negative performance trade-offs due to increased recoil, weight/size/length

- *Increased muzzle rise*
- *Point-of-aim deviation*
- *Slower recovery for follow-on shot*
- *Mobility degraded*
- *Negotiation of obstacles degraded*
- *Restrictions for close-quarters battle (CQB)*
- *Slower point-of-aim changes for dynamic targets*

Fatigue

- ***Continuous target tracking/engagement degraded***
- ***Sustained observation degraded***
- ***Point-of-aim deviation***
- ***Degraded mobility***

Passive Exoskeletons

- ***Gravity balancing***
- ***Achieved with simple spring and dampening elements***
- ***“Weightless” end load***
- ***Weight redistribution***
- ***Balanced for any position***
- ***Demonstrated in simple exoskeletons***

Lockheed FORTIS

Passive Stabilization Concepts

- **Passive exoskeletons potential**
  - **Passive structural aim stabilization**
  - **Weapon weight re-distribution**
  - **Recoil energy re-direction, absorption**
  - **Improved target engagement accuracy (short and long-range marksmanship)**
  - **Improved target engagement timing**

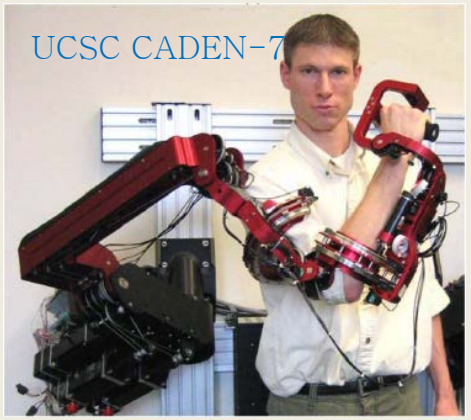
Tilta Armor Man

http://drbrbr.deviantart.com/art/Future-Solder-Concept-409038757

Active exoskeletons

- *Typically large/bulky*
- *High power requirements/tethered*
- *Rehabilitative/load carriage applications*
- *Potential to train limb motion*
  - *Perceptual learning*
  - *Training transfer (+/-) to traditional marksmanship techniques*
- *Potential for active fire control*
  - *Improvement in P(H)*
  - *Shoot-on-the-move capability*
  - *Natural, intuitive interface (pointing/aiming)*
  - *Prolonged stable aiming*
  - *Fire from concealment*

UDel/Columbia CAREX

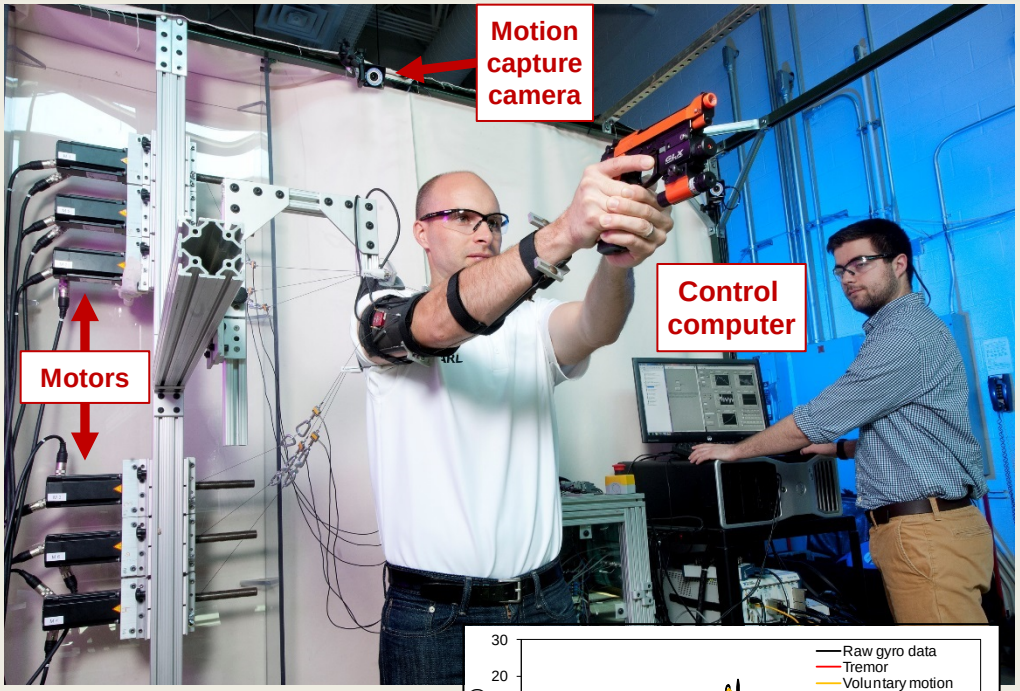


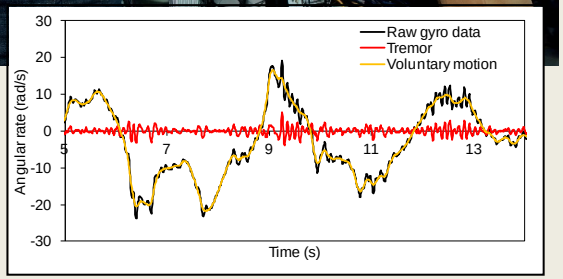
Lockheed HULC

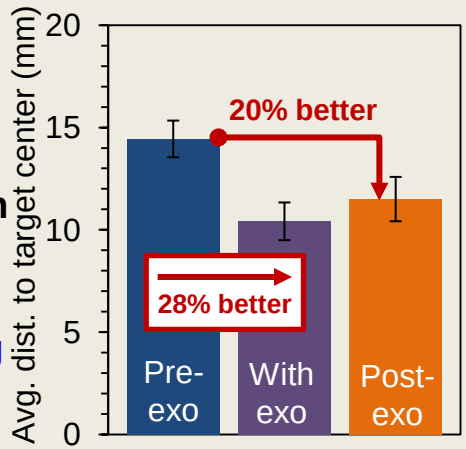
HAL
(Japan: Cyberdyne)

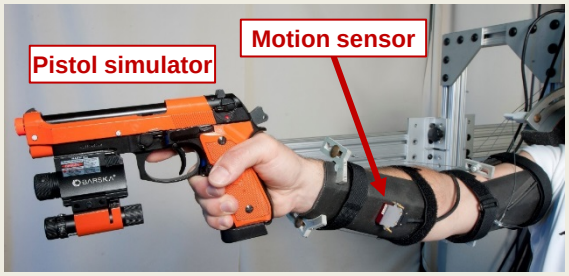
Active Stabilization

- **ARL MAXFAS: Mechatronic Arm eXoskeleton for Firearm Aim Stabilization** (Baechle, 2013; Baechle, Wetzel and Agrawal, 2013)
  - Cable-driven arm exoskeleton to augment human performance: improve firearm aim and reduce fatigue
  - Motors mounted behind wearer, tension cables connected to arm braces (like puppeteer)
  - Sensors on braces monitor & separate involuntary tremor from voluntary motion
  - Predictive algorithms model involuntary tremor, damp tremor but still allow voluntary aiming motions; Tremor filtering and estimation algorithms reduce arm shaking by 16-51% across all degrees of freedom of shoulder and elbow (Baechle, 2013)
  - Improvement after removing exo: potential fatigue reduction or training applications









Conventional vs. Stabilized Target Engagement

- **Conventional (Shoulder-Fired)**
  - Surface contact locations: Two hands, cheek, shoulder
  - Eye-Surface contact location-sighting system-target calibration (zero consistency) for accurate aimed fire
  - Mobility limited by weapon handling/slung weapon
  - Firing from concealment requires at least partial head/body exposure
  - Conventional rifle design: Overall length (OAL: ~30+")
  - Weight burden on human skeleto-muscular system (mitigated by sling)

- **Stabilized (Exoskeleton-Augmented)**
  - Surface contact locations: Firing hand (cheek, shoulder*) = free support hand
  - Eye-sighting system-target calibration (zero consistency) for accurate aimed fire = simplified target acquisition
  - Mobility improved by weapon integration/securely stowed weapon
  - Firing from concealment: Remain in defilade while engaging target using fire control enhancement
  - Reduction of overall length (OAL: 12-18") by integrating recoil mitigation with worn systems
  - Weight burden redistributed to worn systems through integrated design

*Fire control augmented: Firing hand only

U.S. ARMY RDECOM

Future Efforts

ARL

Experimental performance comparisons

- *Motion capture, EMG*
- *Live-fire target engagement trials*
- *Mobility, portability trials*
- *Comparative examination of firing postures/positions*
- *Mixed terrain navigation, target detection*
- *Sustained aim trace analysis*
- *Short- and long-range marksmanship applications*

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Backup

Backup Slides

Human-weapon Interface for Projectile Weapon Systems

- *Target engagement process:*
  - *Detection*
  - *Target Acquisition*
  - *Action*

Stability and Repeatability

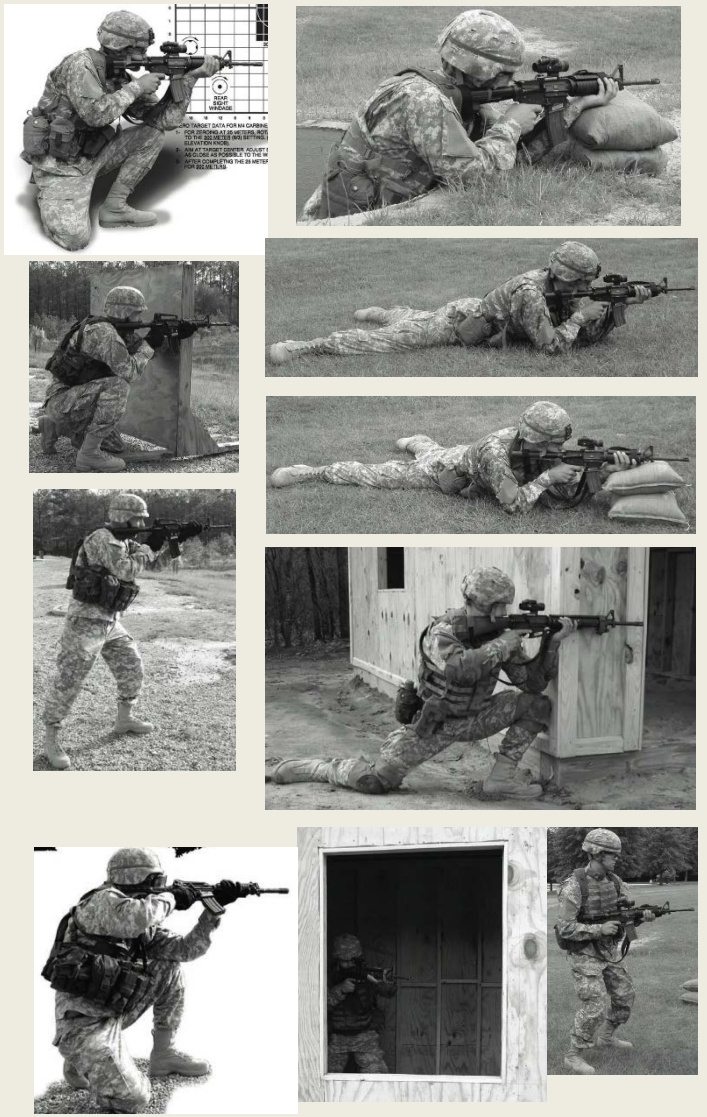
- *Stability*
  - *Involuntary movement degrades accuracy*
  - *Compounded by fatigue, muscular weakness, inattention*

- *Repeatability*
  - *Shot-to-shot inconsistency degrades both accuracy and timing*
  - *Compounded by fatigue, muscular weakness, and inattention*

Firing Postures – Seeking Stability through Support

Shoulder-fired postures/positions

- *Field Manual (FM) 3-22.9*
- *Unsupported vs. supported*
- *Rifle sling*
- *Barriers*
- *Chemical, Biological, Radiological, and Nuclear (CBRN), Ballistic (Facial) Protection Systems*
- *C-clamp*



FM 3-22.9, *Rifle Marksmanship M16-/M4-Series Weapons*, HQDA

All reflect unique firing dynamics, adaptation to achieve stability