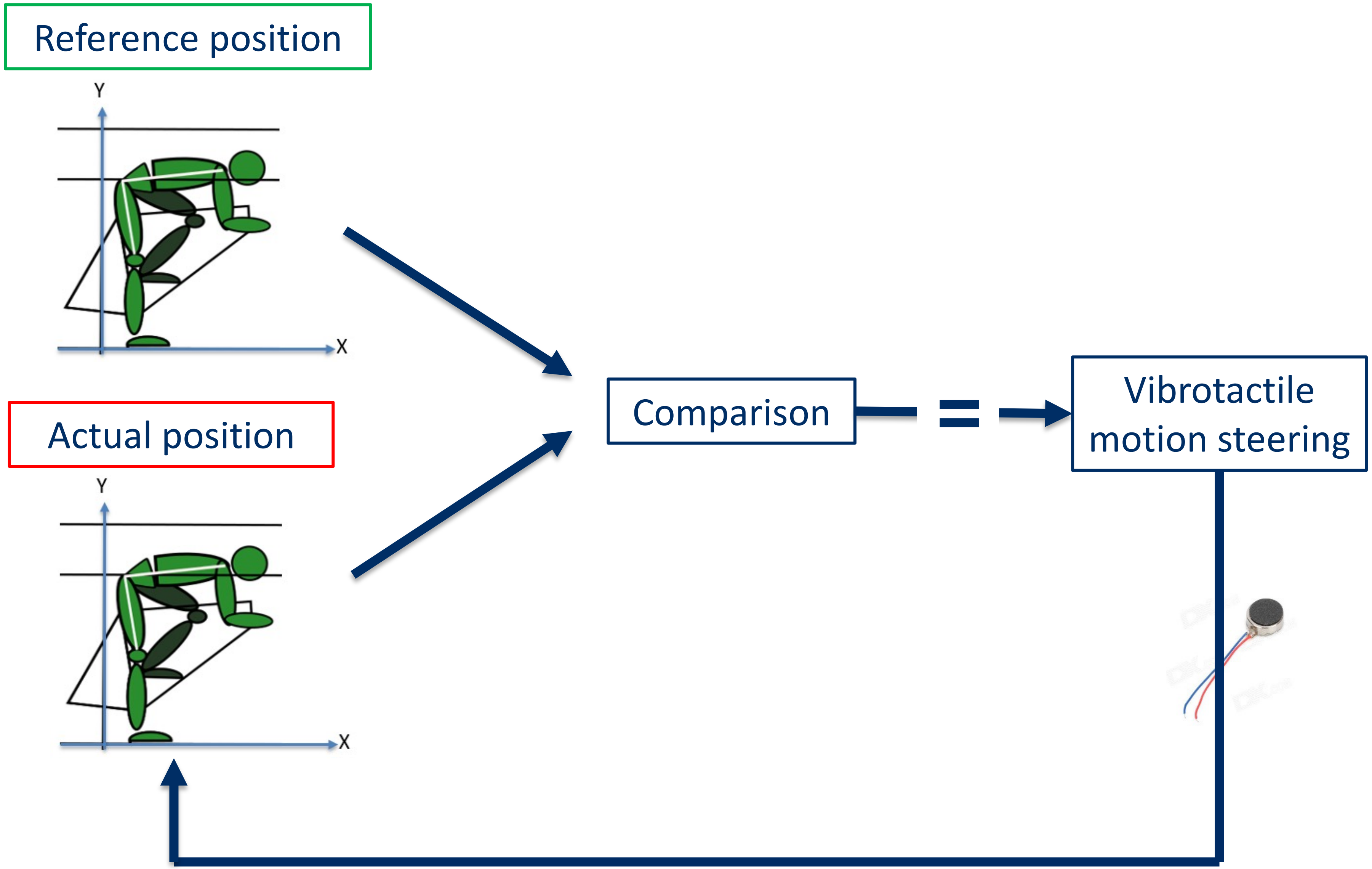
University of Antwerp
Faculty of Design Sciences

Design guidelines for vibrotactile motion steering

Thomas Peeters (PhD fellow)
Stijn Verwulgen (presenter)

Vibrotactile motion steering (VMS)



Vibrotactile motion steering (VMS)

= Providing instant feedback on human posture and movement using vibrations

- **In situations where it is complicated to accurately and consistently assess the quality of maintaining a predefined position or movement**
  - Busy environment
  - Complex task

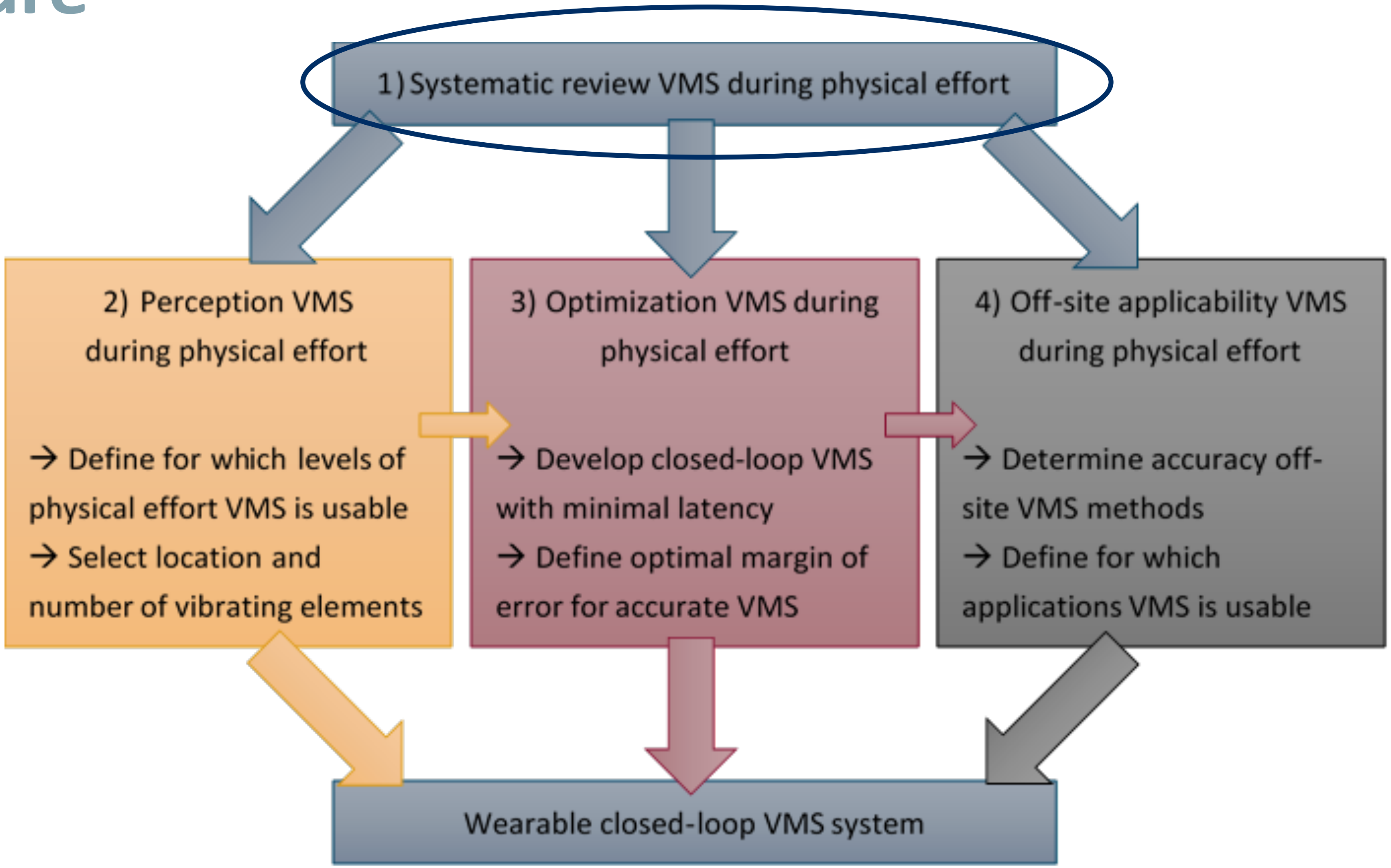
Vibrotactile motion steering (VMS)

= Providing instant feedback on the human posture and movement using vibrations

- **In circumstances where alternative sensory input is difficult**
  - Visual feedback
  - Auditory feedback

→ Real-time VMS is addition when visual and auditory communication are overstimulated

Structure



1) Systematic review VMS during physical effort
2) Perception VMS during physical effort
→ Define for which levels of physical effort VMS is usable
→ Select location and number of vibrating elements
3) Optimization VMS during physical effort
→ Develop closed-loop VMS with minimal latency
→ Define optimal margin of error for accurate VMS
4) Off-site applicability VMS during physical effort
→ Determine accuracy off-site VMS methods
→ Define for which applications VMS is usable
Wearable closed-loop VMS system

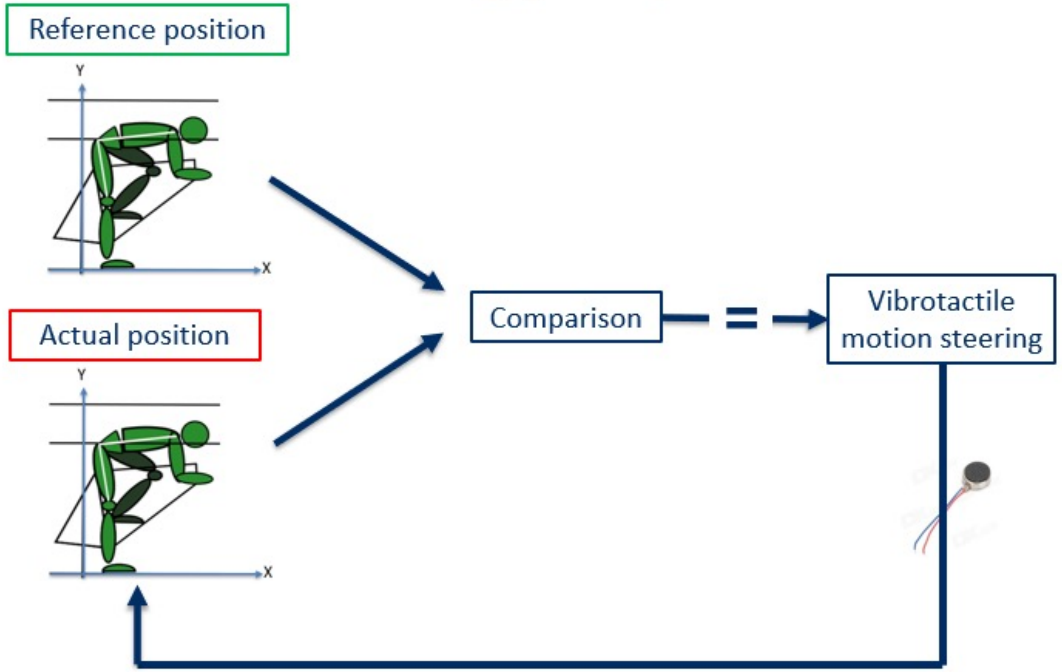
1) Systematic review VMS during physical effort

Studied in stationary situations

Gap: during physical effort

1) Systematic review VMS during physical effort

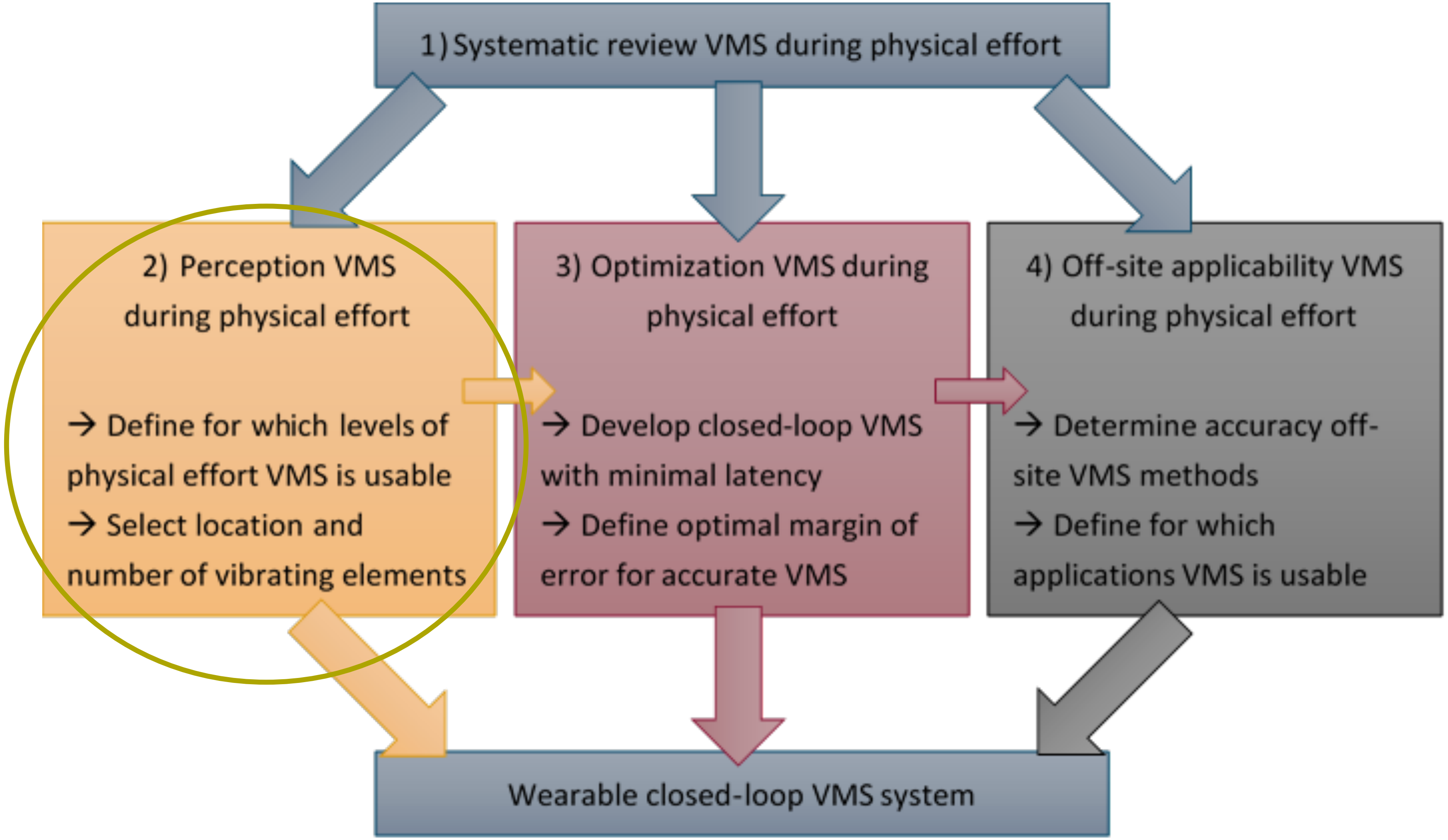
- **Limited research on VMS in subjects performing physical effort**
- **Case study in cycling: aerodynamic position as reference position**



1) Systematic review VMS during physical effort

- **Case study in cycling: aerodynamic position as reference position**
  - Mostly defined in wind tunnel experiments
  - No control on maintaining of this position during training or races
  - Relevant application of VMS
  - Aerodynamic pose is definable, reproducible and assessable
  - Straightforward to simulate different levels of physical effort

Structure



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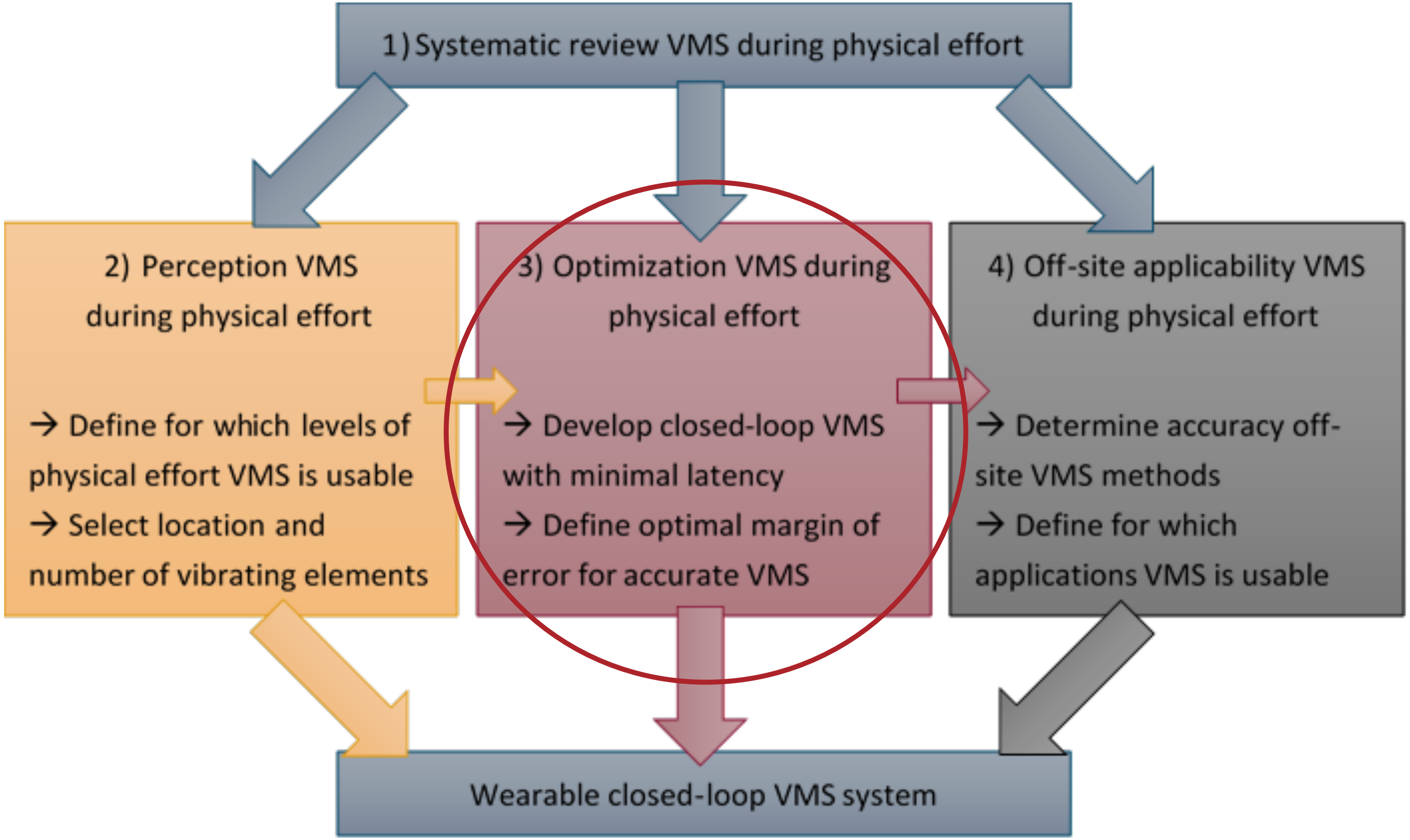

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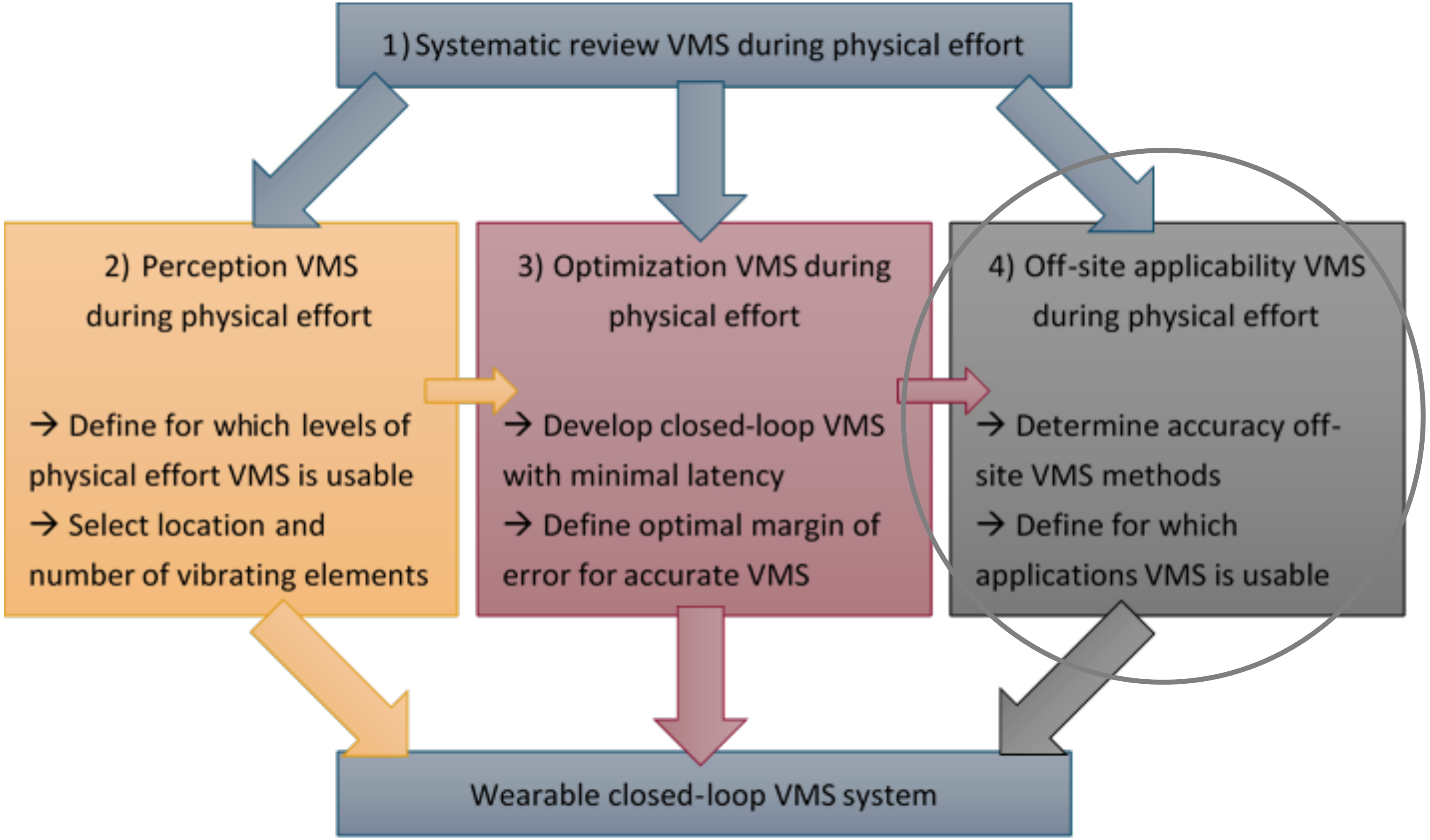

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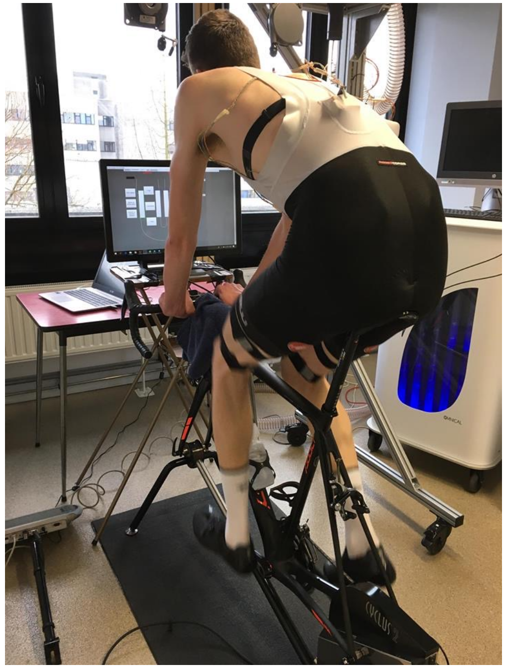
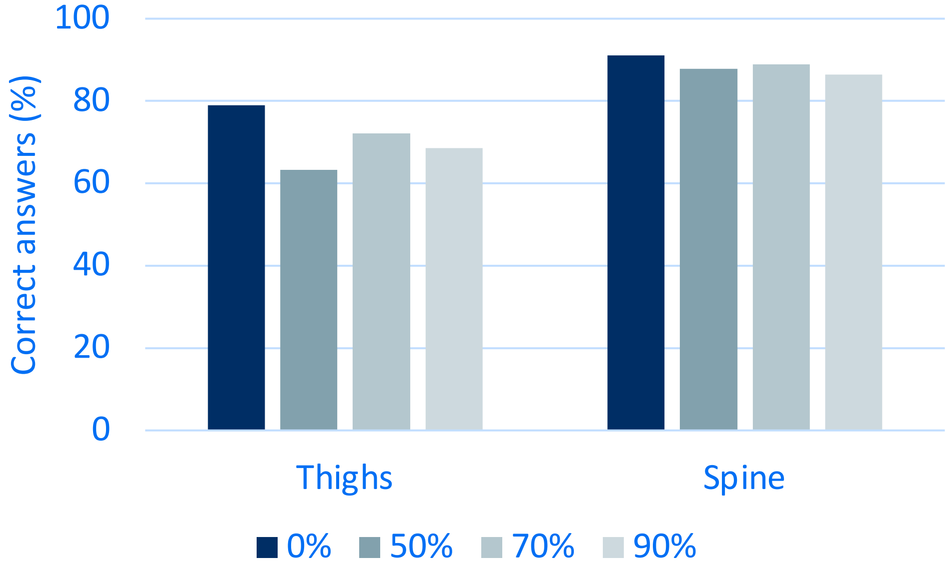
2) Perception VMS during physical effort

- **Vibration motors as in smartphone activated at thighs and spine during 4 levels of physical effort**
  - Stationary (0% of P_{max})
  - Cycling at 50% of P_{max}
  - Cycling at 70% of P_{max}
  - Cycling at 90% of P_{max}

- **Participants indicated location on touchscreen**

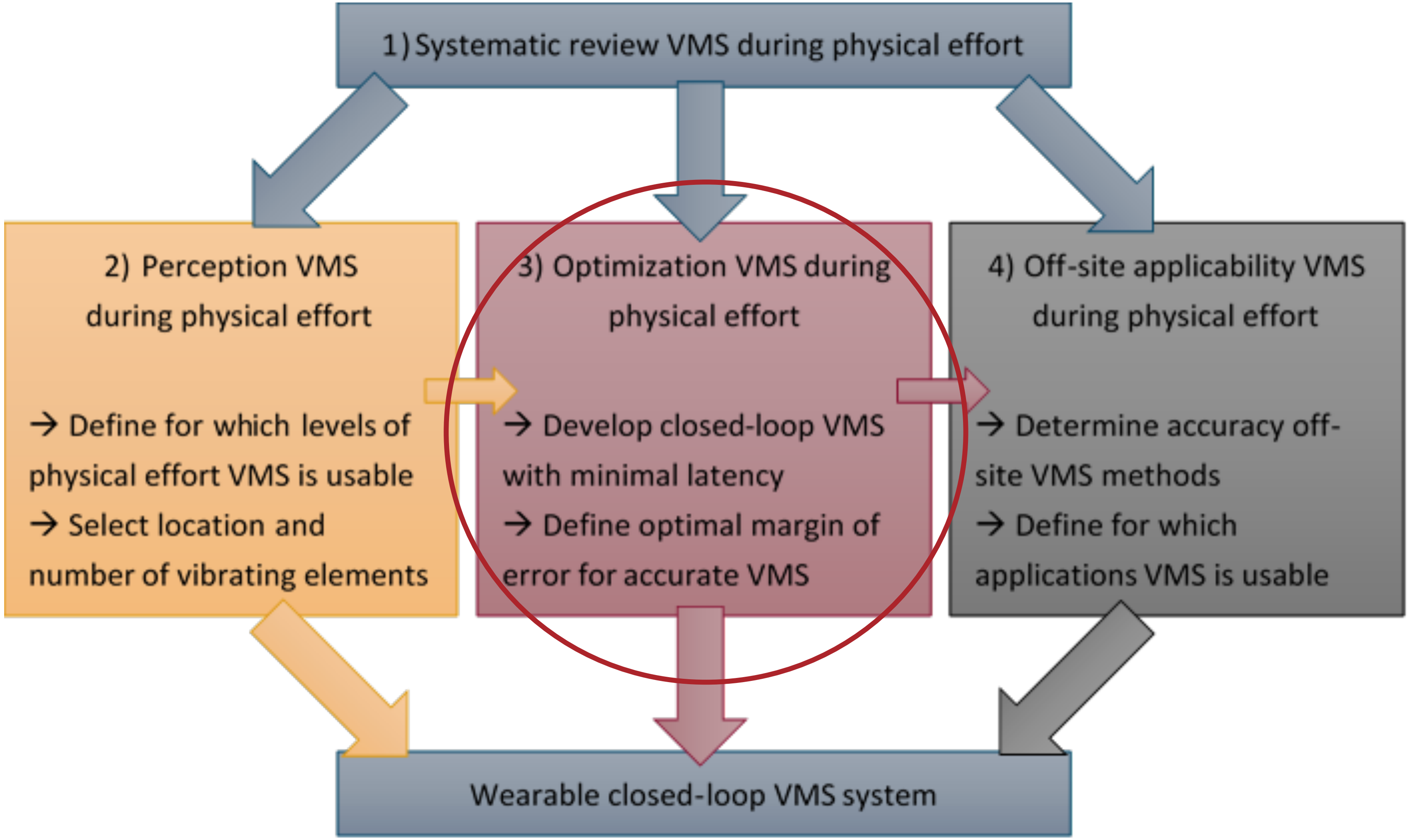


2) Perception VMS during physical effort



- **Single vibrating signals perceived almost perfectly**
- **Accurate perception during high levels of physical effort for thighs and spine ($p > 0.1$)**
- **Vibrating signals at spine better noticed compared to thighs ($p < 0.01$) and preferred for aerodynamic corrections**

Structure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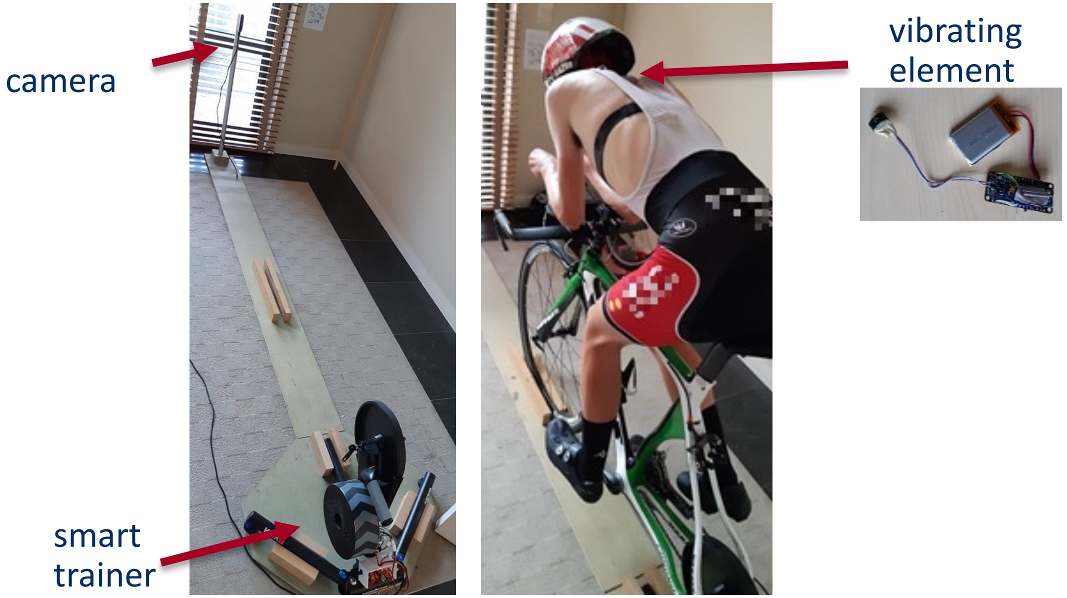
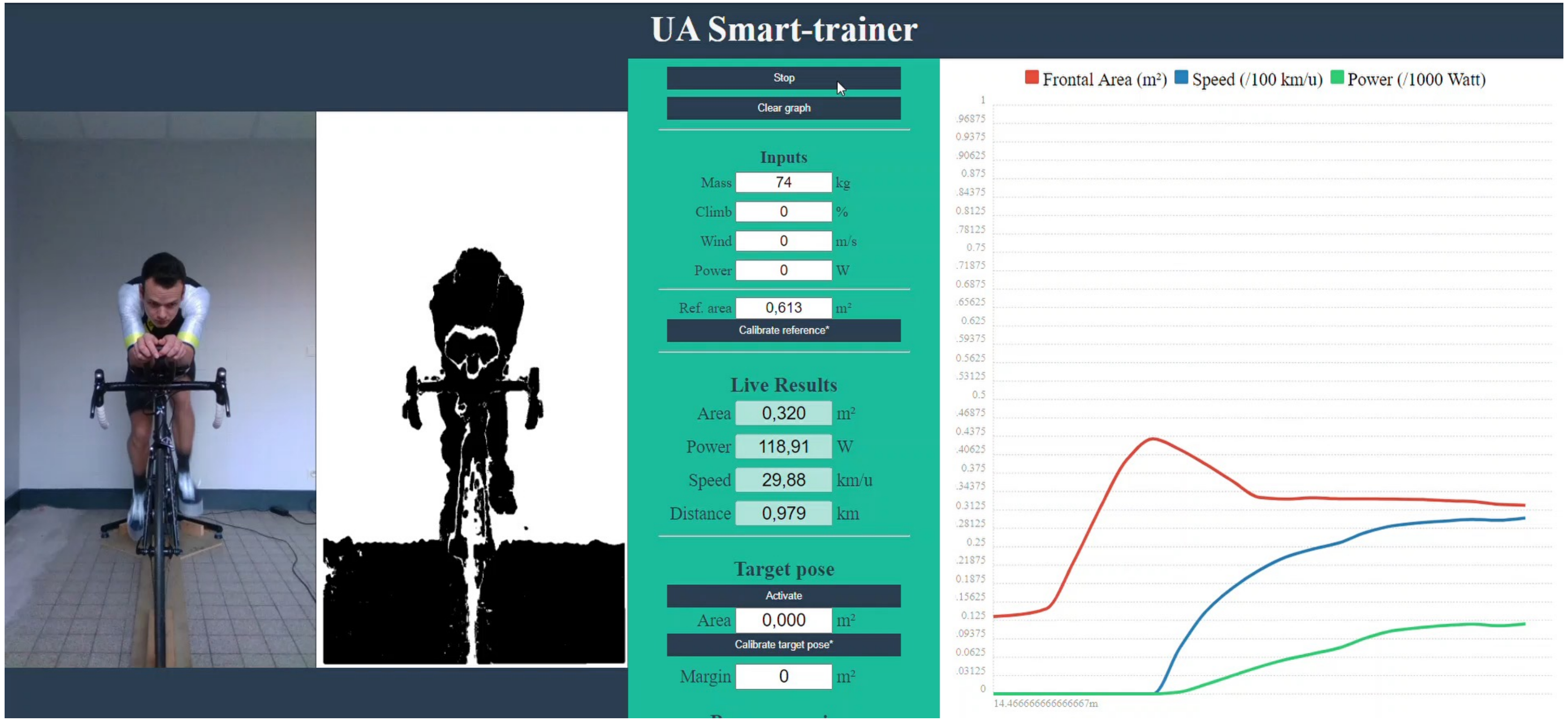
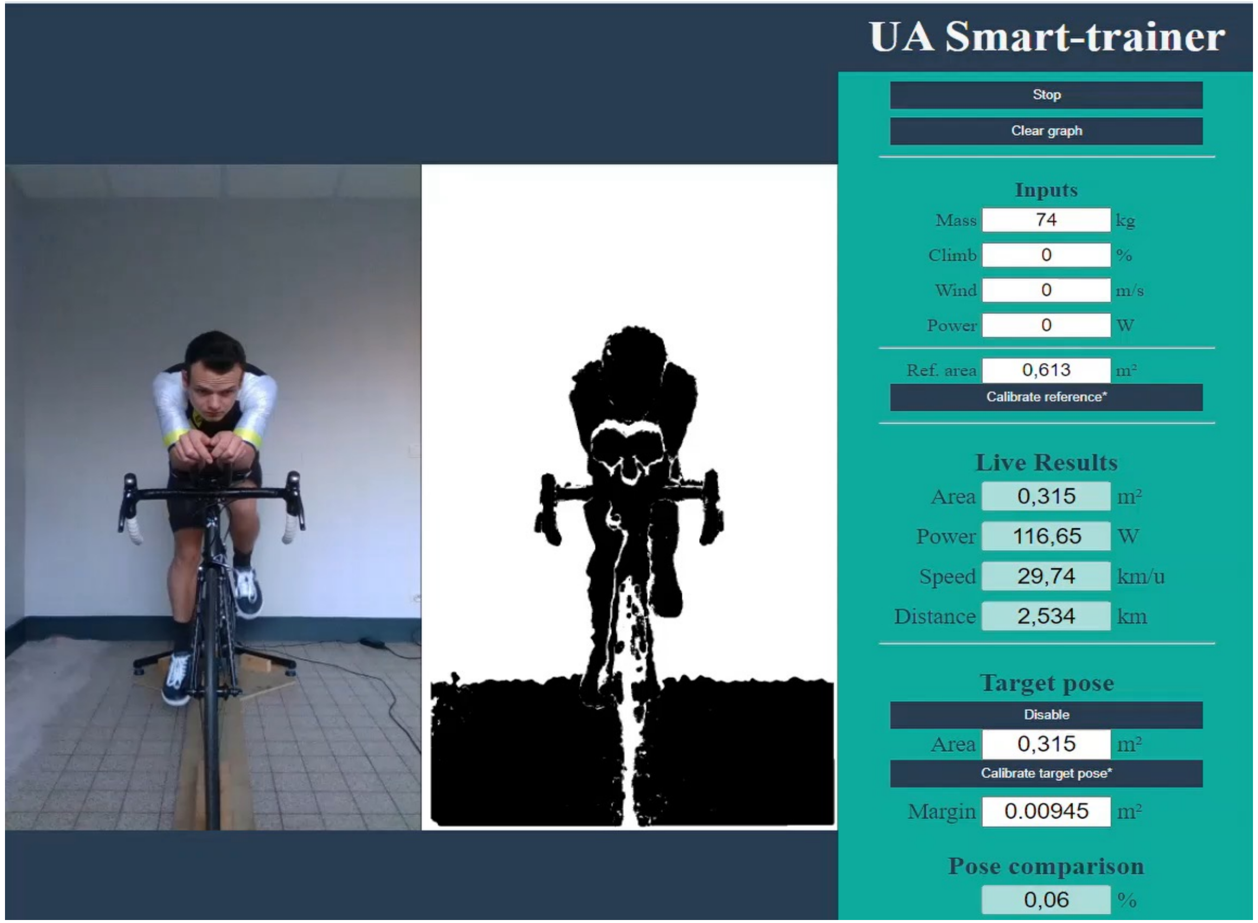
3) Optimization VMS during physical effort

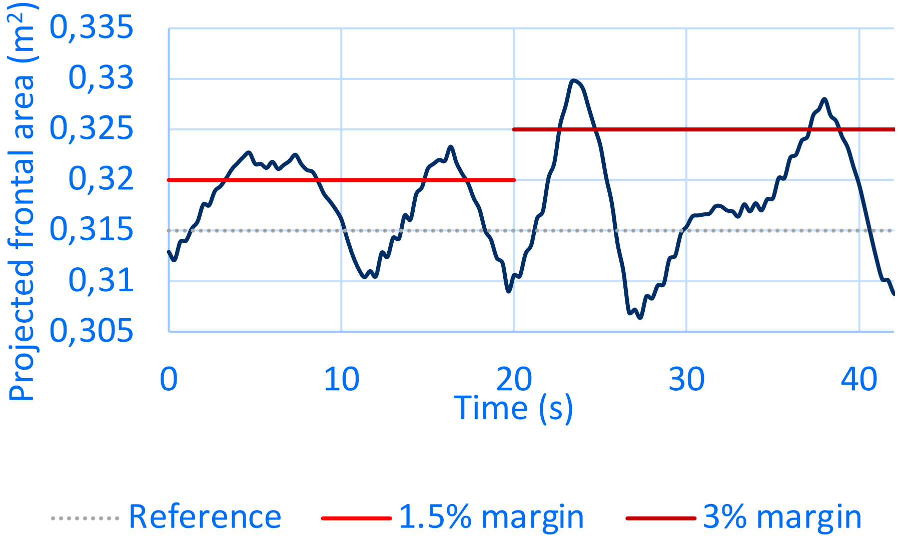
- **Indoor training setup with frontal camera**
  - To calculate projected frontal area as indication of aerodynamics
  - To define aerodynamic reference position
- **Real-time VMS at C7 (neck) to provide feedback on cyclists' position**
- **Resistance smart trainer adjusted based on frontal area**





Pose	Frontal area (m^2)	Power (W)
TT	0.315	119
Drops	0.393	147
Hoods	0.410	154
Tops	0.416	155





Reference pose = 0.315 m^2

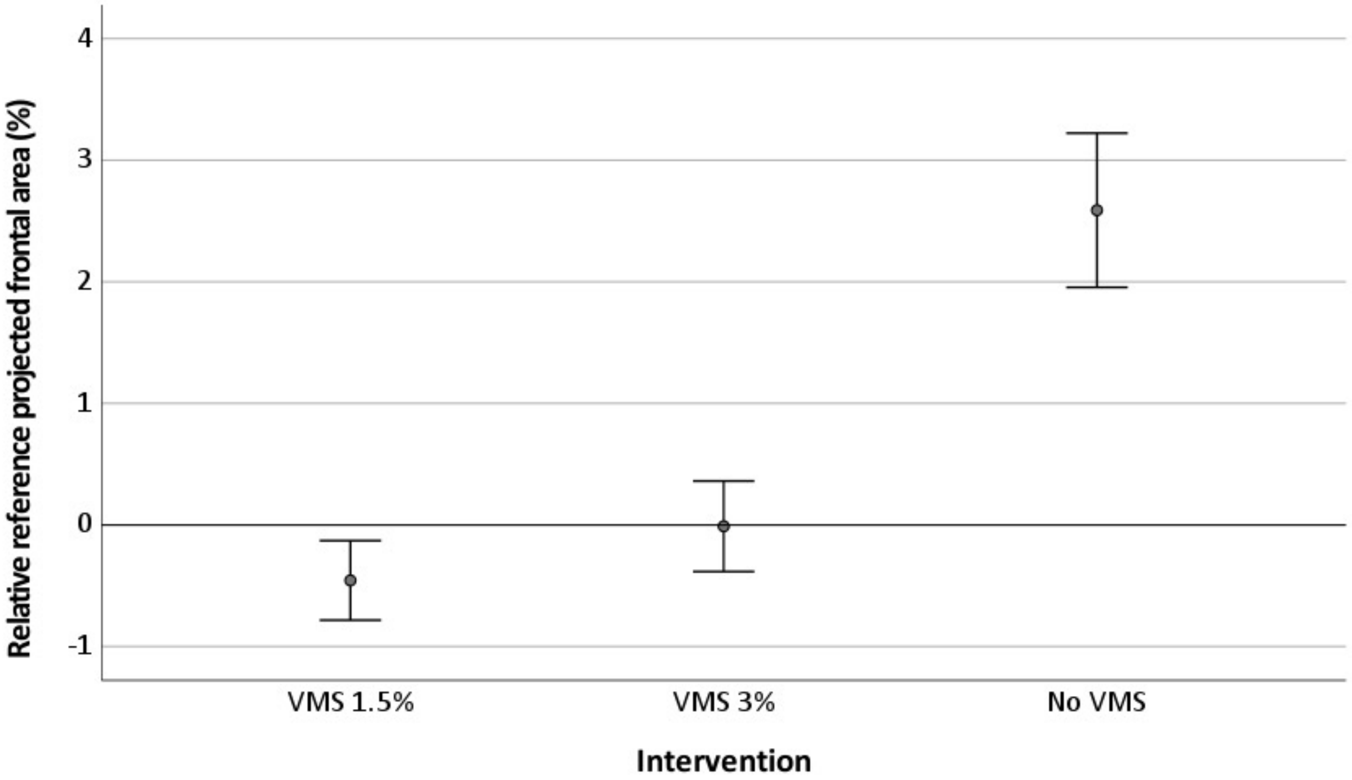
Margin of error	Margin above reference pose (m^2)	VMS from (m^2)
1.5%	0.004725	0.320
3%	0.00945	0.325

3) Optimization VMS during physical effort

- **Investigate efficiency VMS and define optimal margin**
- **3 interventions in random order**
  - No VMS
  - VMS from 1.5% above reference frontal area
  - VMS from 3% above reference frontal area

- **12' protocol**
  - Reference position
  - Sit upright
  - Standing

3) Optimization VMS during physical effort



- **Reference position is more accurately achieved using VMS compared to no VMS ($p < 0.001$)**

- **No significant difference between 1.5% and 3% margin ($p = 0.11$), preference is person-specific**

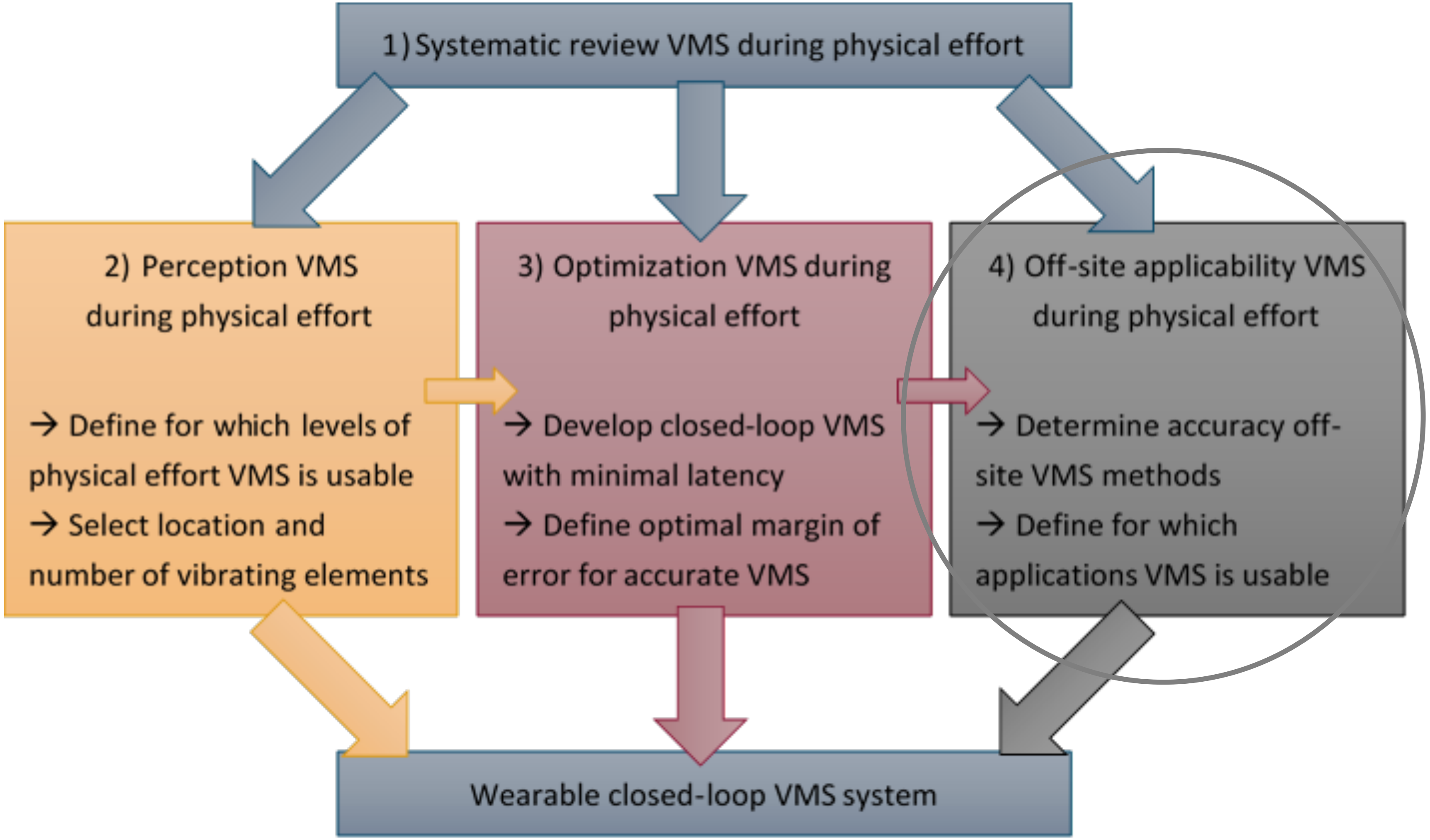
3) Optimization VMS during physical effort

Profit VMS compared to no VMS at 50km/h

Intervention	Δ frontal area (m^2)	Δ power (W)
1.5% - No	-0.0068	-11.75
3% - No	-0.0046	-8.05

Theoretical effect of ± 20s for 1h

Structure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4) Off-site applicability VMS during physical effort

- **Frontal area as function of body measurements and joint angles via inertial measurement units (IMUs)**
  - Position and orientation specific body parts

- **Analyse effect different cycling positions and joint angles**
  - Back bending
  - Knee pronation
  - Neck extension

4) Off-site applicability VMS during physical effort

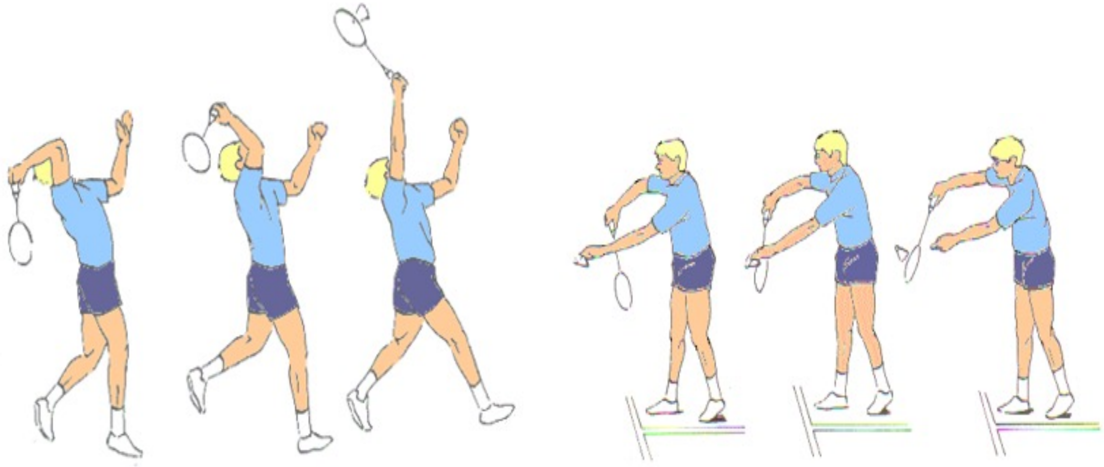
- **Linear regression analysis estimates frontal area based on body measurements and joint angles with average relative error of 1.70 ± 8.72%**
- **Not sufficient for aerodynamic VMS**
  - Margin of error of 1.5% or 3%
  - Induce false positive and false negative VMS (up to 52.6%)
  - Wider margin irrelevant since average deviation from reference pose without VMS is around 3%

4) Off-site applicability VMS during physical effort

- **Methods to directly estimate aerodynamics in outdoor situations**
- **Body Rocket system**
  - Aerodynamic drag cyclist
  - Force sensors on contact points between cyclist and bike
  - Compatible with VMS

Conclusion

- **VMS effective in providing feedback on aerodynamic pose**
  - Accurate perception at high cycling intensities
  - VMS based on real-time data is efficient
  - Outdoor potential should be further investigated
- **VMS can be optimized for alternative applications in other sports**



Conclusion

- **Recommendations for optimal use of VMS during physical effort**
  - Ensure vibrating motors make direct contact with skin
    → Provide accurate perception of vibrations for user
  - Use only one parameter simultaneously to provide VMS
    → Avoid confusing user
  - Optimize accuracy of measurements
    → Avoid false positive or false negative VMS

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Questions?

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