

Warehouse Picking: Evaluating Accuracy, Speed, and Workload Across Instruction Modalities

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Executive Summary

- Order picking is a major contributor to warehouse labor cost and worker strain.
- This study evaluates how picking strategy (discrete vs. batch) and instruction modality (paper, HHD, AR) affect performance and workload.
- Results show clear trade-offs between speed, accuracy, and workload.
- Augmented reality (AR) improves picking performance and helps manage workload, especially under complex batch conditions.

Background

- Traditional picking methods (paper, handheld devices) require frequent attention shifts.
- These interruptions increase cognitive load and error likelihood.
- Discrete picking (one order at a time):
 - Higher accuracy
 - Lower cognitive demand
 - Lower efficiency
- Batch picking (multiple orders):
 - Higher efficiency
 - Increased cognitive and physical demand
- AR provides hands-free, spatially aligned information, reducing visual search and mental effort.
- Limited research compares AR vs. traditional methods across different picking strategies.

Experiment Design

- 2 × 3 factorial design Tasks:
 - Simulated warehouse order picking
 - Batch condition: 2–4 orders simultaneously
- 12 Participants
- Dependent variables:
 - Picking speed (Pick/min)
 - Errors (accuracy)
 - NASA-TLX (workload)

Experimental Setup

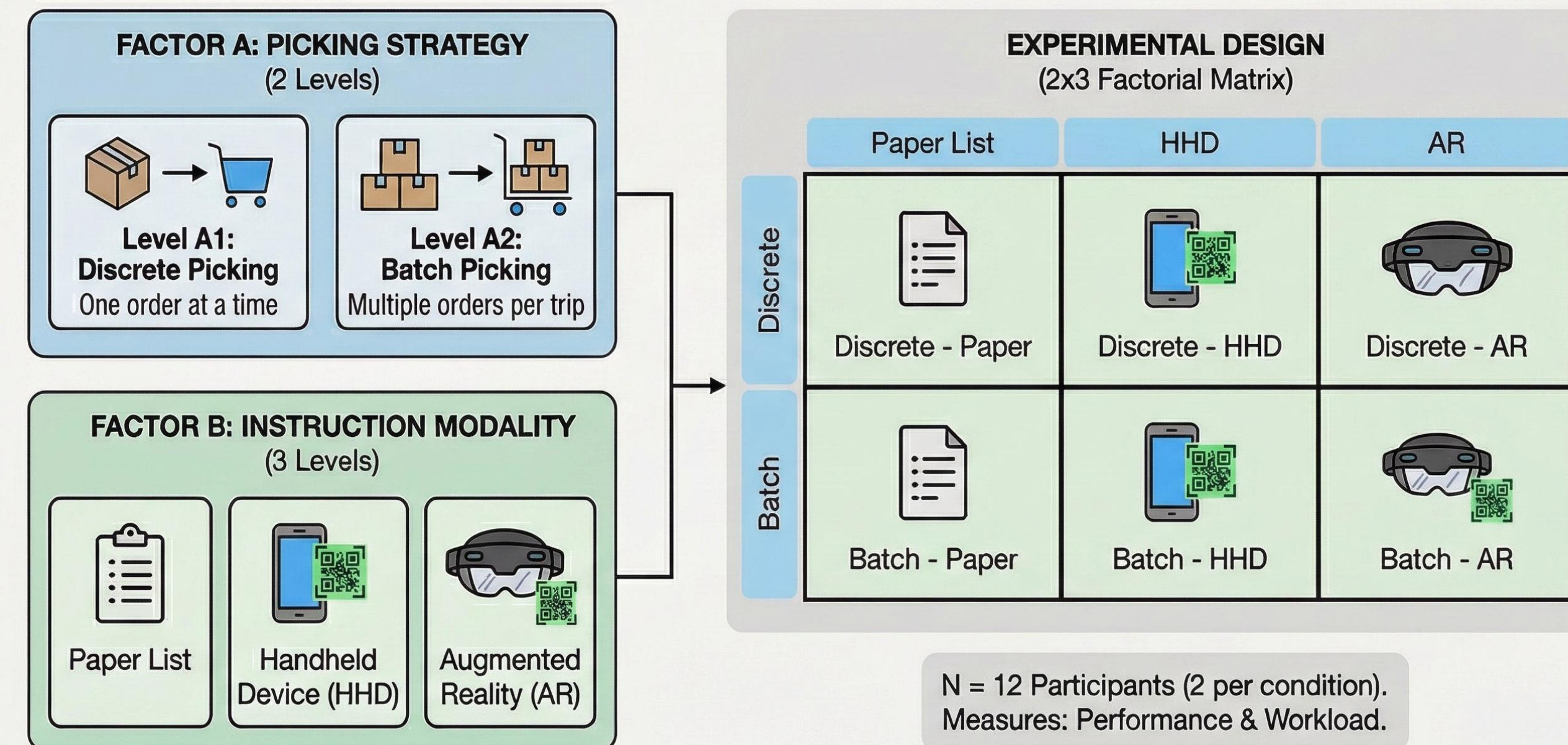


Figure 1. Diagram of the 2×3 factorial experimental design.

- Controlled laboratory warehouse environment
- Defined aisle structure and item locations
- Participants completed picking tasks under assigned conditions
- AR system:
 - Head-mounted display
 - In-field visual guidance
- Paper and HHD:
 - External information sources
 - Required attention switching
- Task conditions were kept consistent across participants

Experimental Test Plan

- Performance (Pick/min)
 - Significant interaction between strategy and modality ($F(2,11)=5.68$, $P<0.05$)
 - AR achieved the highest picking speed in discrete conditions
 - Paper performed better in batch conditions
 - HHD showed consistently lower performance

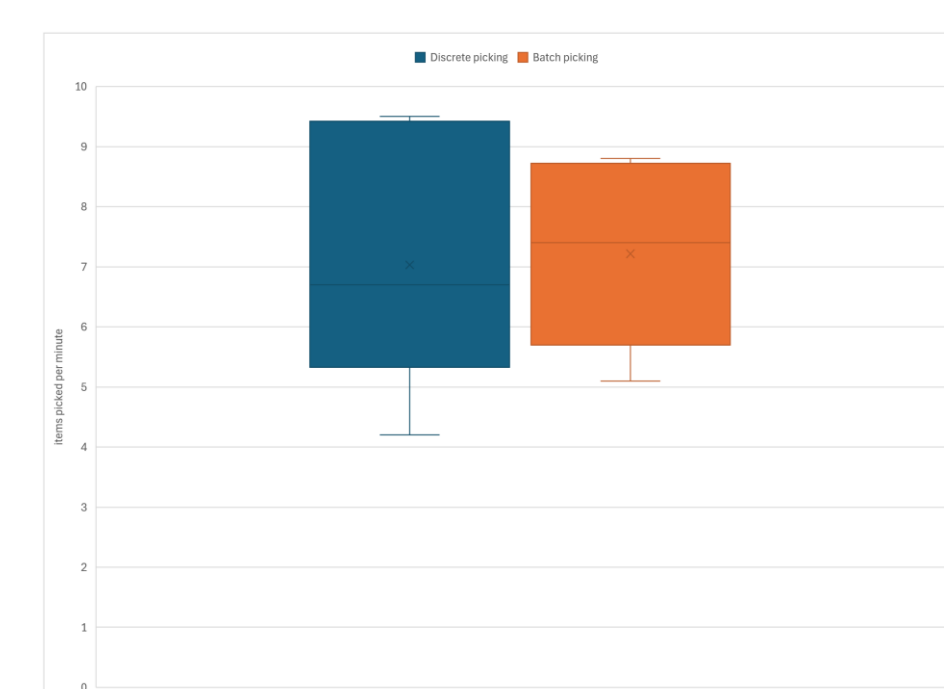


Figure 3. Items Picked per Minute based on picking strategy

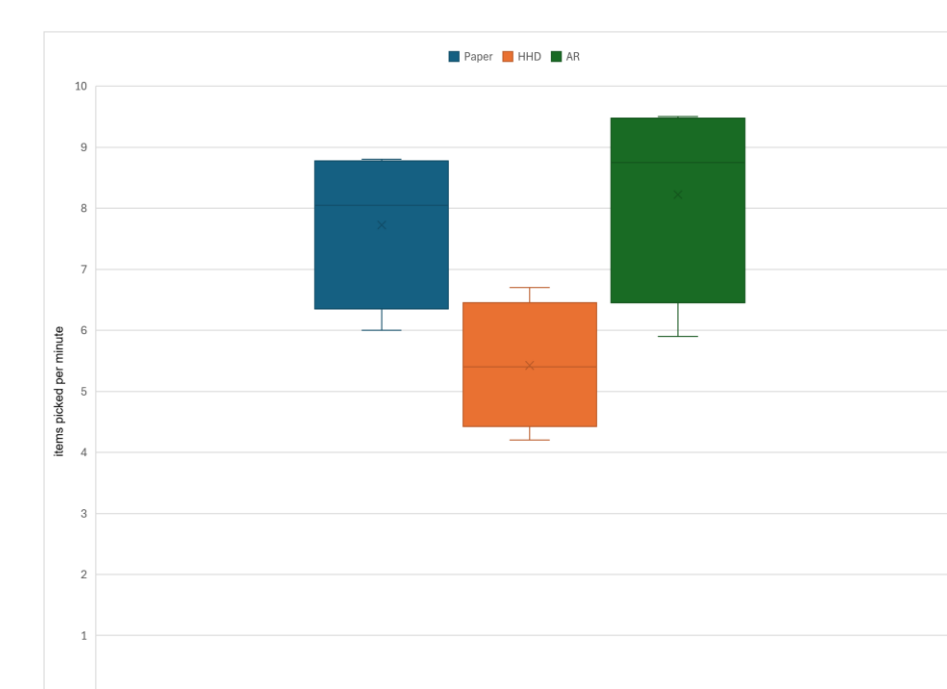


Figure 4. Items Picked per Minute based on instruction modalities

Experimental Results

- Accuracy (Errors)
 - Discrete picking resulted in fewer errors
 - Batch picking showed higher error counts
 - AR generally reduced errors compared to traditional methods

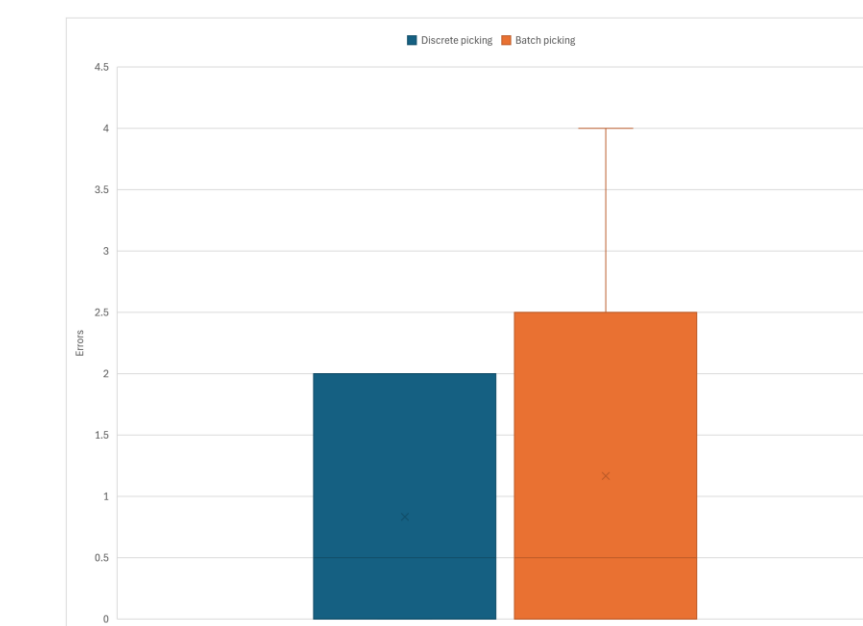


Figure 5. Number of errors based on picking strategy

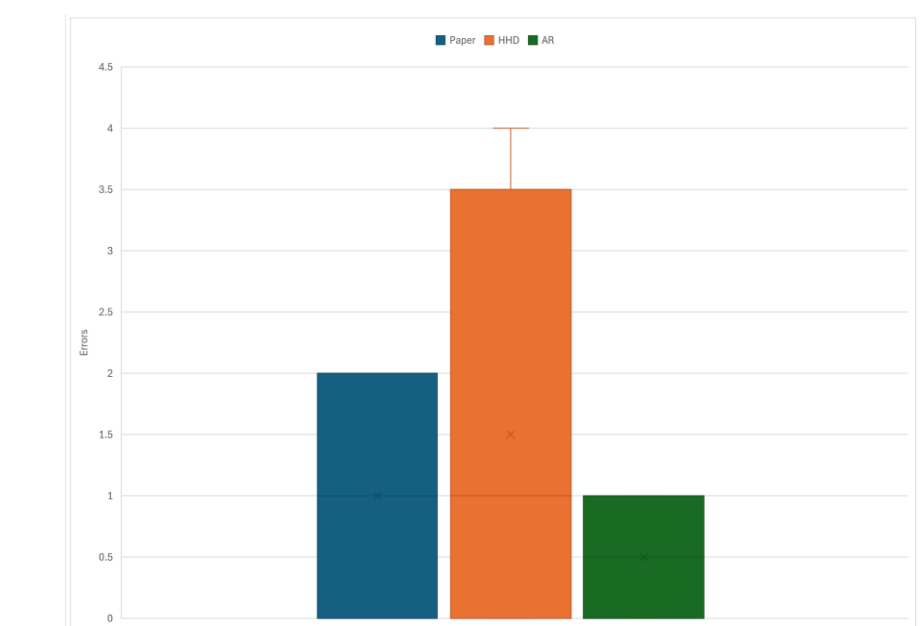


Figure 6. Number of errors based on instruction modalities

- Workload (NASA-TLX)
 - Batch picking increase Mental demand, Temporal demand and workload
 - AR showed lower workload levels, especially in batch picking

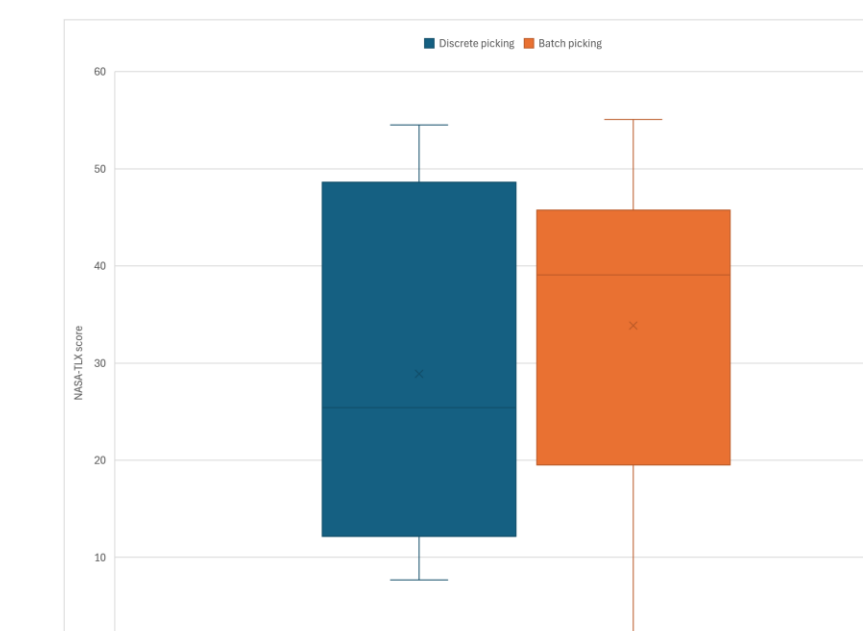


Figure 7. NASA-TLX score based on picking strategy

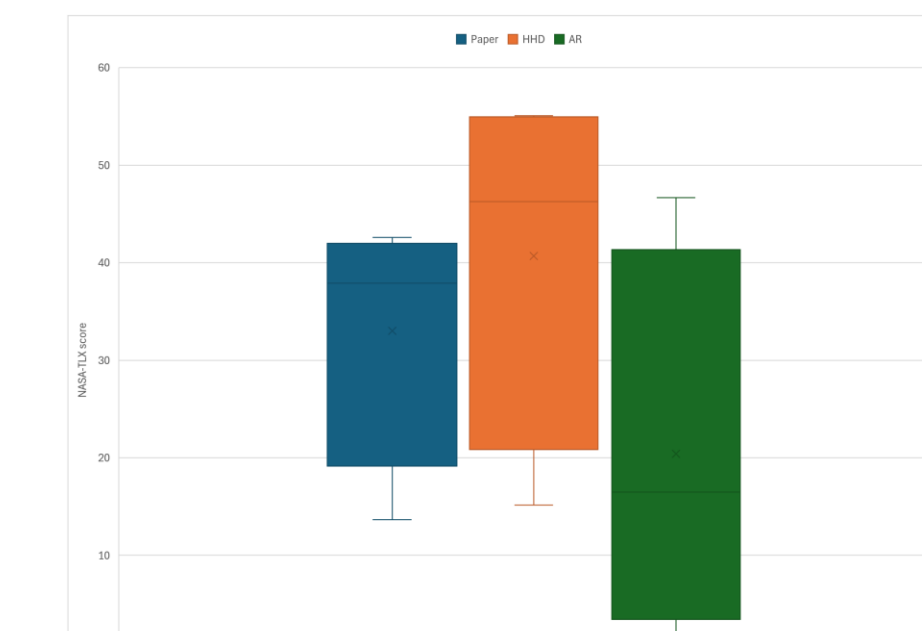


Figure 8. NASA-TLX score based on instruction modalities

Conclusions

- Picking strategy introduces trade-offs between efficiency, accuracy, and workload
- Batch picking improves speed but increases cognitive and physical demand
- Discrete picking improves accuracy but reduces efficiency
- AR helps balance these trade-offs, improving performance while managing workload
- AR is most beneficial in complex picking environments

References

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