Effectiveness of social distancing through the lens of ABM

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Abstract

We quantitatively calculate the transmission risk of an infectious disease among individuals moving within a confined setting (office, religious site, classroom, etc), inspect methods for **lowering the risk** and examine the **costs of such measures**. Combining human mobility (Fig. 1-a) and a compartmental epidemic model (Fig. 1-b), we devise an *agent based model* consisting of pedestrian dynamics and spreading phenomena and introduce a **novel definition of social distancing force**.

Model

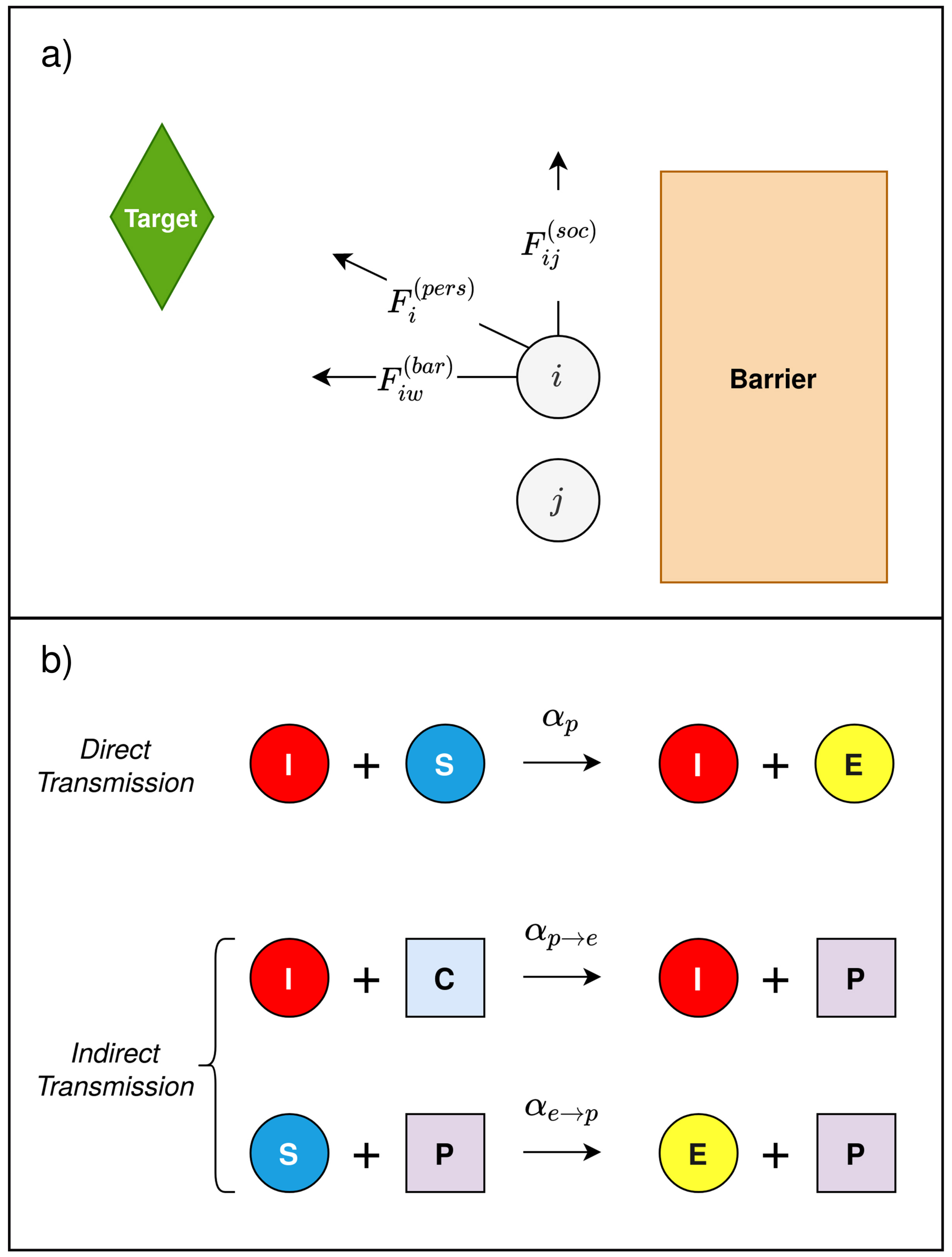

Figure 1: a) Mobility model: Each agent i chooses a random target and moves toward it ($\mathbf{F}_i^{(pers)}$) while keeping distance from other agents ($\mathbf{F}_{ij}^{(soc)}$) and physical barriers ($\mathbf{F}_{iw}^{(bar)}$). b) Spreading model: as direct transmission (person to person) and indirect transmission (person to environment to person) Circles: Agents. S: Susceptible, I: Infectious, E: Exposed. Squares: Tiles of environment. C: Clean, P: Polluted.

Forces and Parameters

- $\mathbf{F}_i^{(pers)} = m_i \frac{\mathbf{v}_i^0 - \mathbf{v}_i}{\tau}$
- $\mathbf{F}_{ij}^{(soc)} = \kappa \sigma_i e^{-\frac{r_{ij}}{\sigma_i}} \hat{\mathbf{r}}_{ij}$
- $\mathbf{F}_{iw}^{(bar)} = \kappa_w \sigma_w e^{-\frac{r_{iw}}{\sigma_w}} \hat{\mathbf{r}}_{iw}$

N	Total number of agents
σ	Social distancing intensity
E_p	Exposure via direct infection
E_e	Exposure via indirect infection
α_p	Direct infection probability
α_e	Indirect infection probability

Results

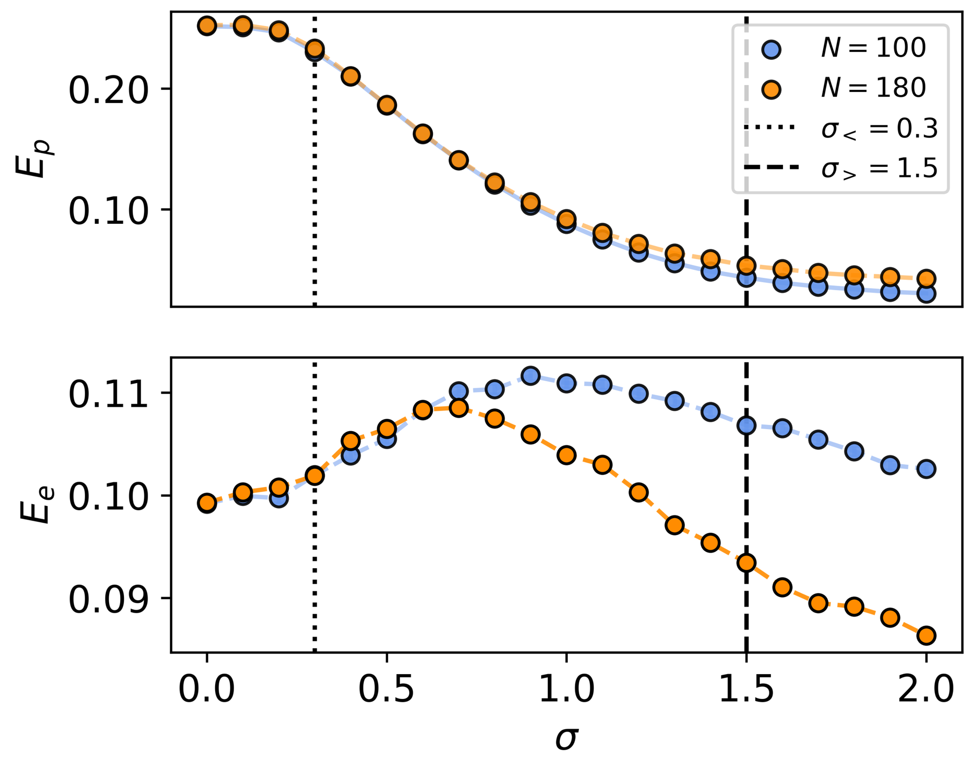

Figure 2: proportion of directly (E_p) and indirectly (E_e) infected agents for varying values of social distancing σ.

Mobility Analysis

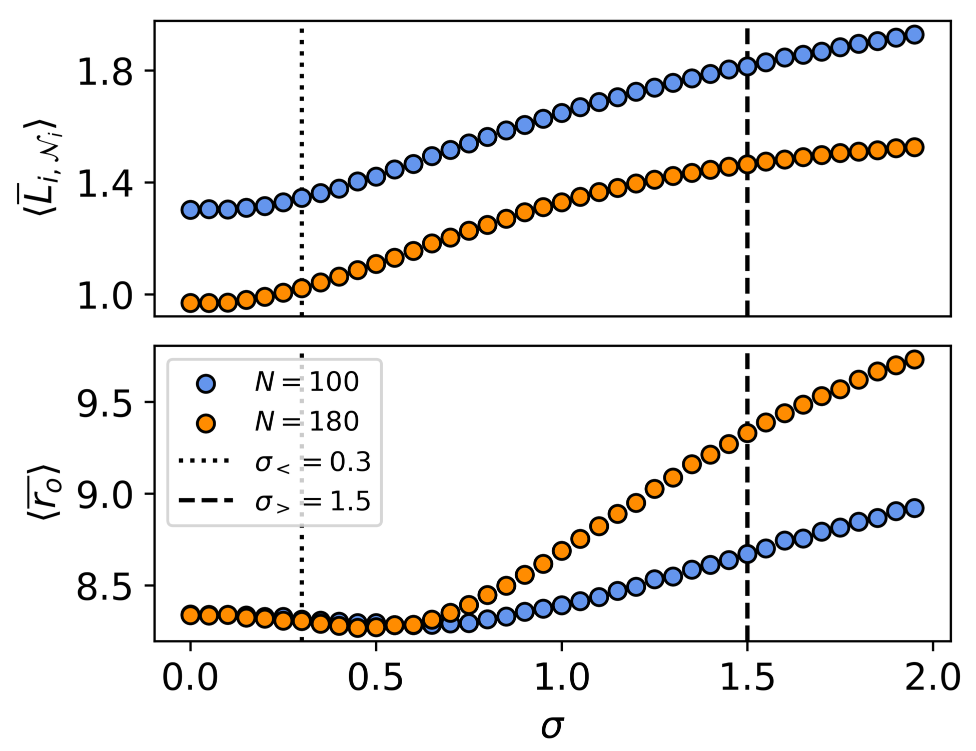

Figure 3: Top: The steady increase in nearest neighbor distance $\langle \overline{L}_{i,\mathcal{N}_i} \rangle$. Bottom: Initial decrease and later increase in distance from the center $\langle \overline{r_o} \rangle$ for varying values of social distancing σ.

Agent-Swarm Interaction

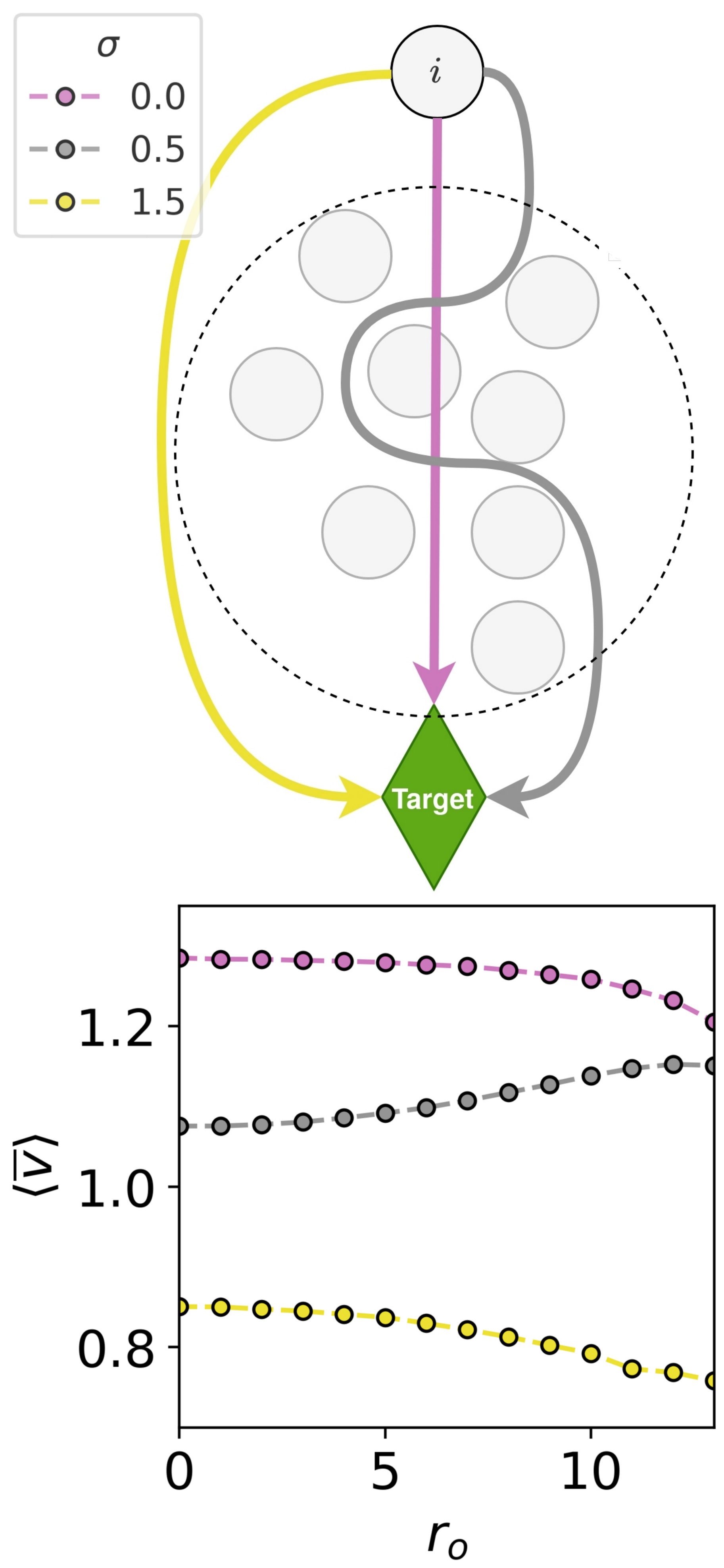

Figure 4: Left: Agent-Swarm interaction schematic for various values of social distancing σ. Right: Speed distribution over position, for various values of social distancing σ.

Transmission Probability Analysis

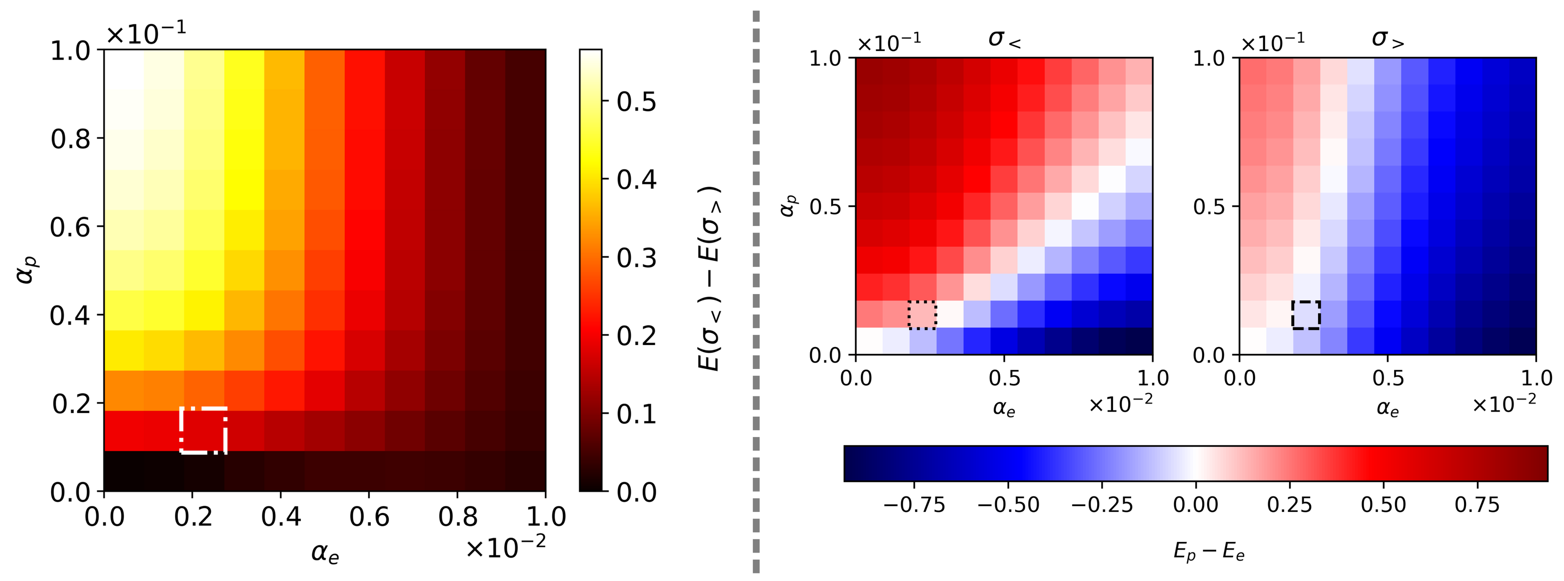

Figure 5: Left: Effect of social distancing on direct (α_p) and indirect (α_e) probabilities. Right: The shift in direct E_p and indirect transmission E_e dominated regimes.

Conclusion

- While the increase of social distancing σ results in a consistent decrease of direct infection (E_p), it results in an initial increase of the indirect infection (E_e).
  - This observation has roots in mobility patterns; while the nearest neighbor distance $\langle \overline{L}_{i,\mathcal{N}_i} \rangle$, related to direct transmission increases, distance from the center $\langle \overline{r_o} \rangle$, an indicator of density, related to indirect transmission decreases.
  - Further experimental studies would be necessary to understand whether this range of parameters conform to real world epidemics.
- Abiding by social distancing drastically affects direct vs indirect transmission dominance.

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References

[1] C. Castellano, S. Fortunato, and V. Loreto, Reviews of Modern Physics, 81 (2009) 591.

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Software

Animation