Electrical Stimulation of Excitable Tissue

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Electrophysiology and Bioelectricity
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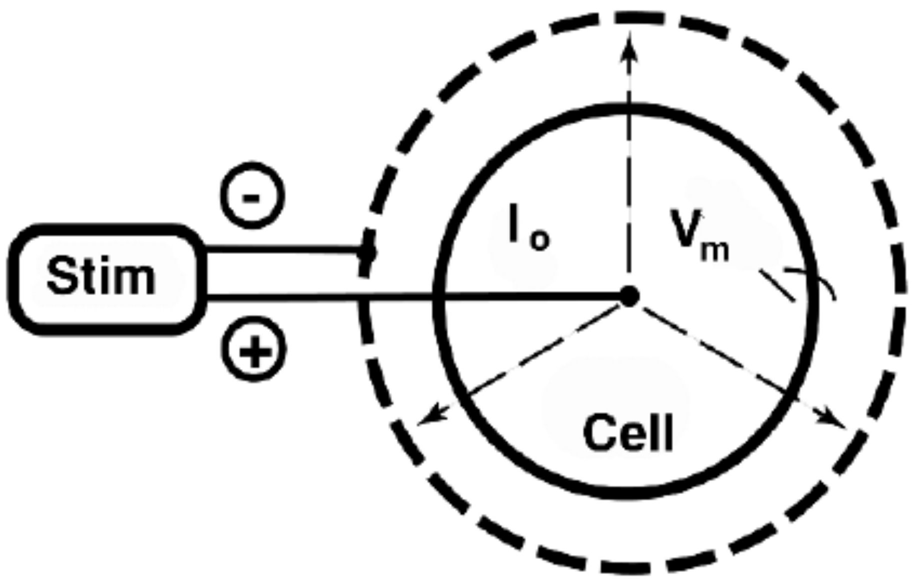
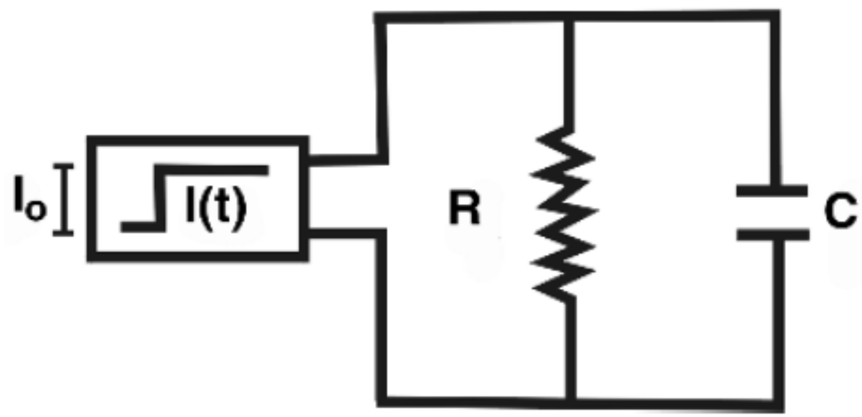
Spherical Cell Model

- Simplifying assumptions:
  - $R=R_m/A$
  - $C=C_m/A$



Spherical Cell Circuit Model

Can treat it as a simple RC network



$$v_m = I_o R(1 - e^{-t/\tau})$$

Where τ=RC,

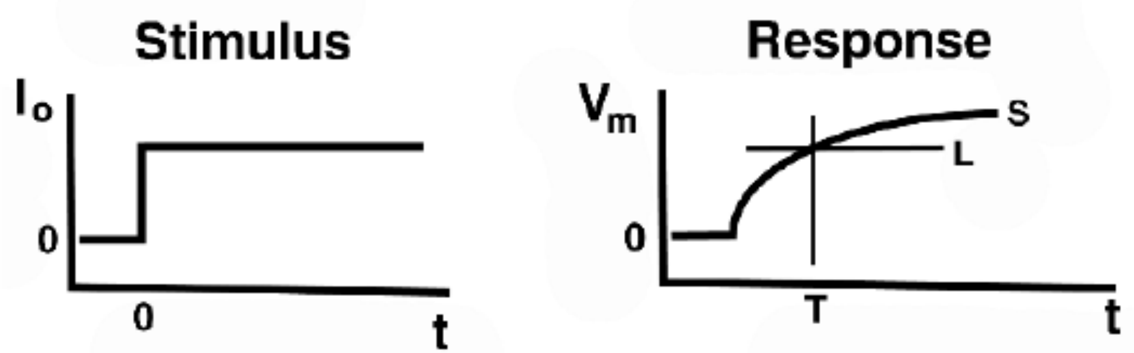
Threshold Voltage and Time

$$V_T = S(1 - e^{-T/\tau})$$

T is the time needed to reach threshold, V_T is the threshold voltage, and $S=I_O R$

Solving for T...

$$T = \tau \ln\left(\frac{S}{S - V_T}\right)$$



Weiss-Lapicque Equation

$$V_T = S(1 - e^{-T/\tau})$$

May be rearranged to

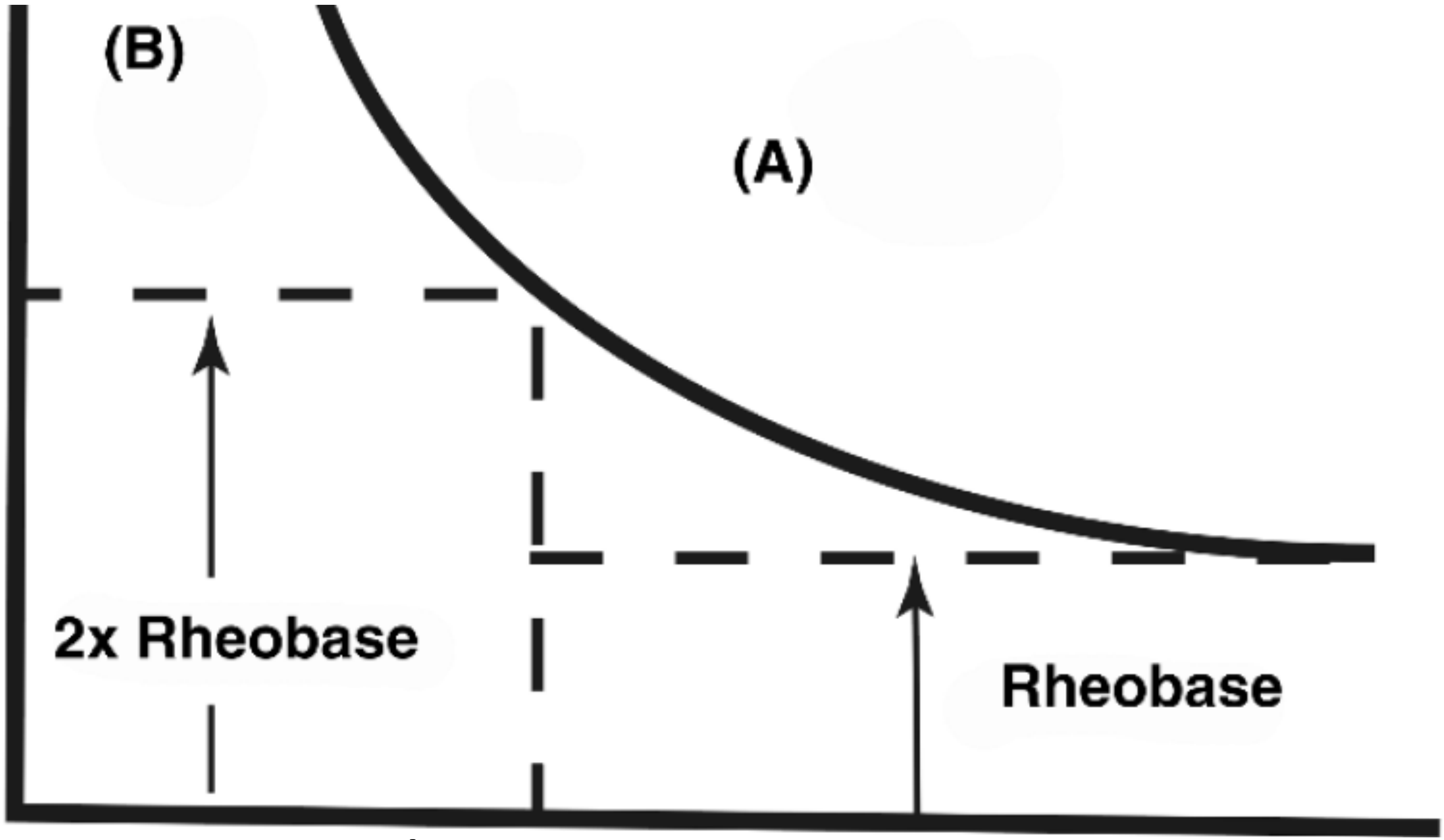
$$S = \frac{V_T}{(1 - e^{-T/\tau})}$$

Dividing by both sides by R

$$I_{th} = \frac{I_R}{(1 - e^{-T/\tau})}$$

I_R is defined as the rheobase. I_{th} is the minimum threshold to achieve threshold with a stimulation of duration T.

Strength-Duration Curves



Chronaxie

Chronaxie

The pulse duration when the stimulation strength is twice rheobase is the chronaxie (T_c).

$$V_T = 2V_T(1 - e^{-T_c/\tau})$$

$$e^{-T_c/\tau} = \frac{1}{2}$$

$$T_c = \tau \ln(2) = 0.693\tau$$

Application of Weiss-Lapicque Equation

REVIEW

Can the Direct Cardiac Effects of the Electric Pulses Generated by the TASER X26 Cause Immediate or Delayed Sudden Cardiac Arrest in Normal Adults?

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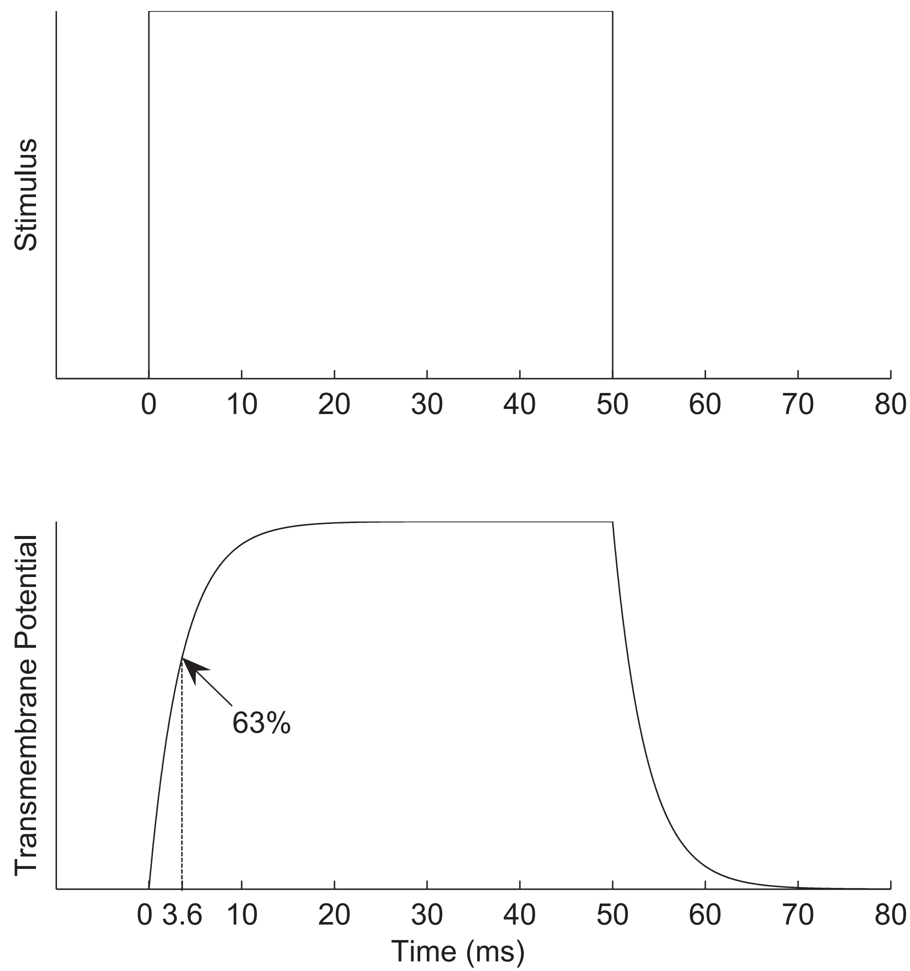
Passive Membrane Response



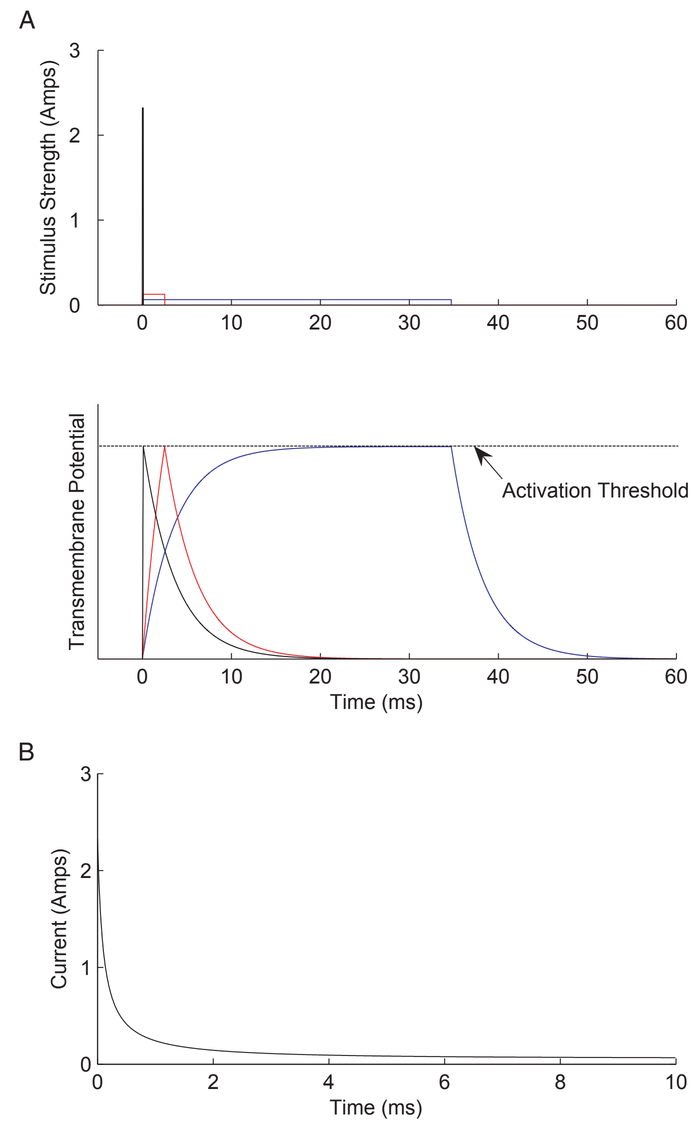
Blair's Equation

$$I_T(d) = \frac{I_r}{1 - e^{-d/\tau}}$$

Where $I_T(d)$ = Threshold current for given pulse duration
I_r=rheobase (63.7ms)
d=pulse duration (0.1, 2.5, and 34.7 ms)
τ = tissue time constant (3.6 ms)

So …

$I_T(d)$ = 2.3, 0.13, and 0.06 A

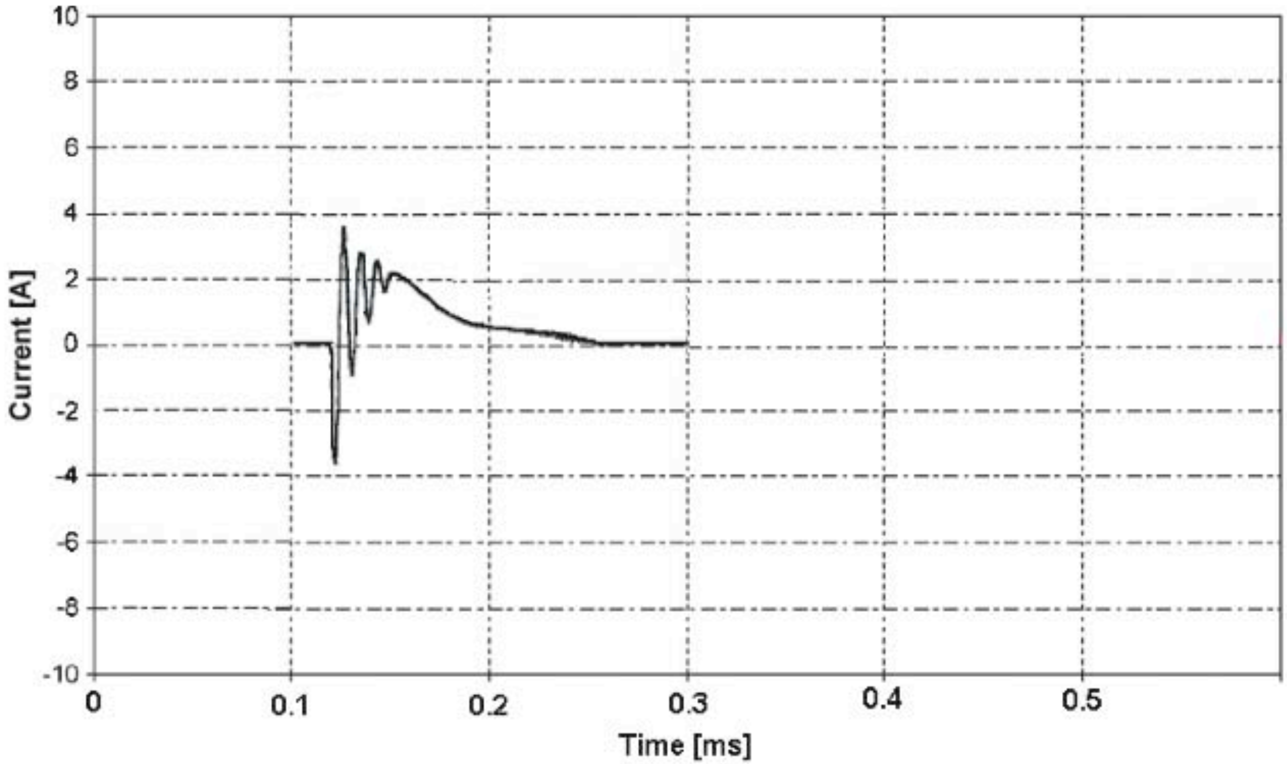


External Pacing Threshold

	pulse width	Threshold	current	Std Dev	n
Luck et al.[1]	40	64±14 (range 40-80)	64	14	17
Prochaczek et al.[2]	40	59±20 (range 28-80)	59	20	6
Altamura et al.[3]	20	74±14 (range 50-100)	74	14	8
Klein et al.[6]	40	68±16 (range 45-100)	68	16	11
Kelly et al.[7]	40	60±3	60	3	23
Falk and Battinelli[9]	40	73±6 (SEM)	73	33.9411255	32
Falk and Batinelli[9]	20	74±7 (SEM)	74	39.59797975	32
Kemnitz et al.[10]	50	57±20 (range 30-90)	57	20	9
Falk and Ngai11	20	Ammeter 77.3±16.4	77.3	16.4	10
McEneaney et al.[12]	40	72.9±22	72.9	22	13
Prochaczek et al.[14]	30	59.7±11.6	59.7	11.6	77
Estes et al.[15]	40	68±15	68	15	22
			63.7 mA	22 mA	260

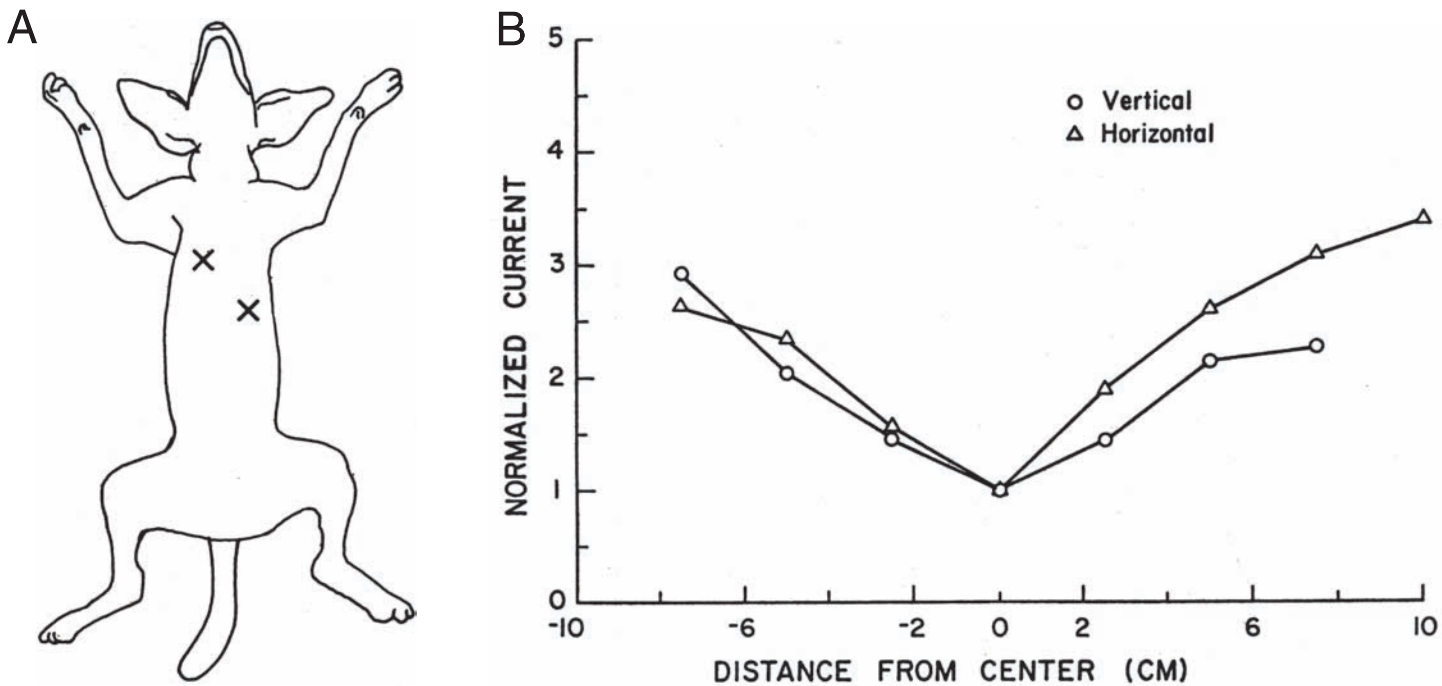
Since the pulse width is >>τ, the external pacing threshold ≈ I_r

TASER Pulse



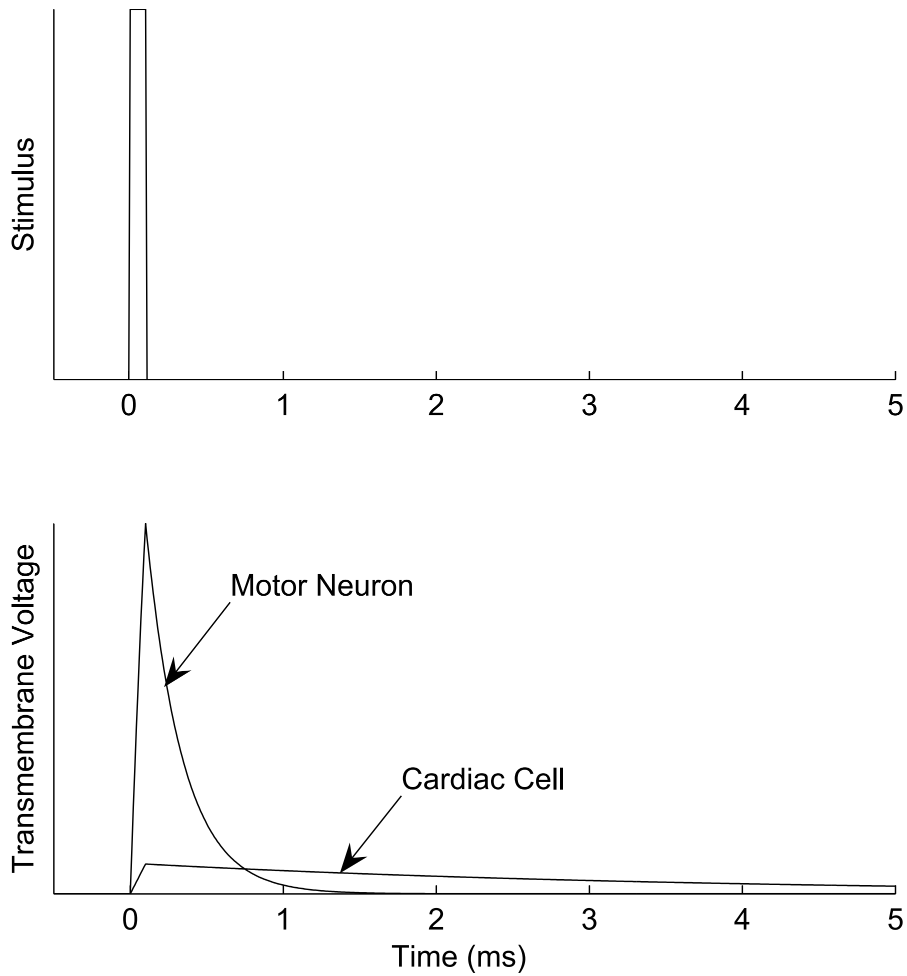
The taser pulse may be approximated by a 1 A, 100 µs square wave

Placement of Pacing Leads



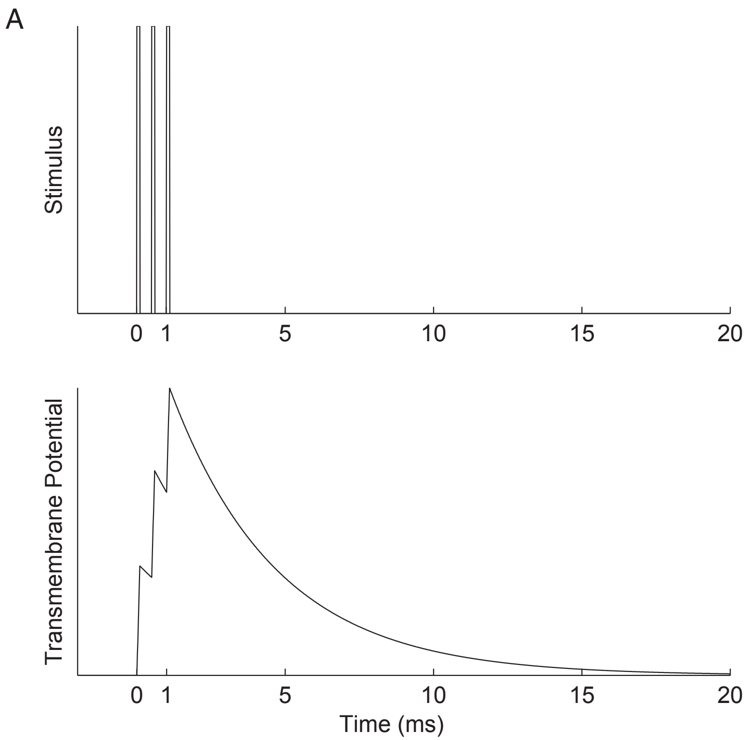
Assume that the TASER darts were placed at the optimal location for stimulation

Motor Neuron vs Cardiac Cell Response

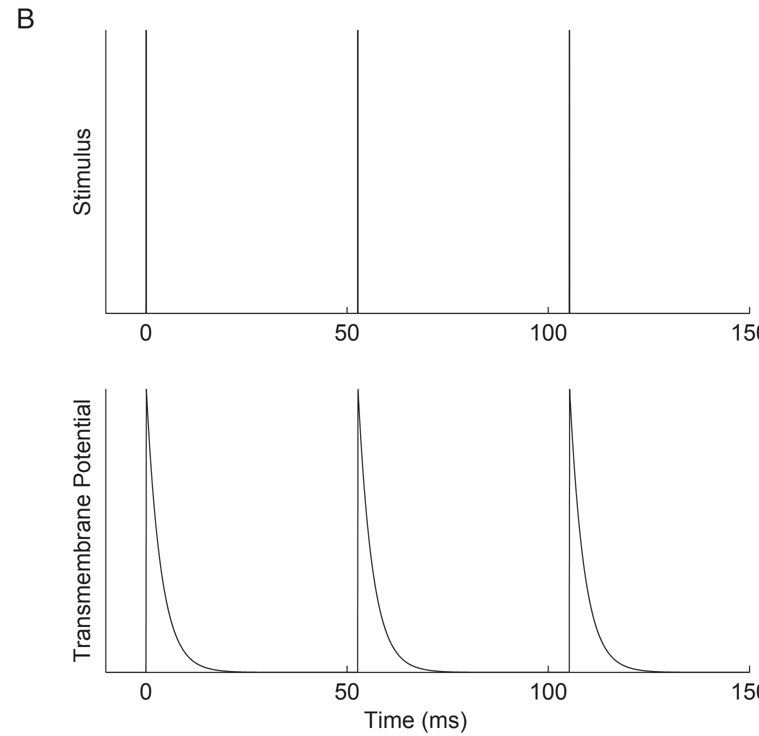


τ = 3.6 ms for cardiac tissue and τ = 0.24 ms for motor neurons, so short pulses have a much larger effect on motor neurons

Temporal Separation



Pulses delivered temporally close together would have an additive effect for cardiac tissue



But TASER pulses are delivered approximately 53 ms apart and have no cumulative cardiac effect

Paper Conclusions

TASER pulses have a strong effect on motor neurons but have a very low probability of stimulating cardiac tissue even with electrodes placed at optimal locations.